FLAME ELECTRICITY AND THE CAMERA

By GEORGE ILES

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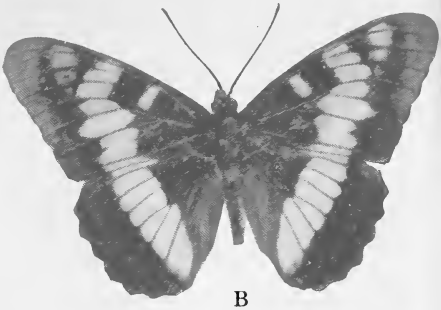
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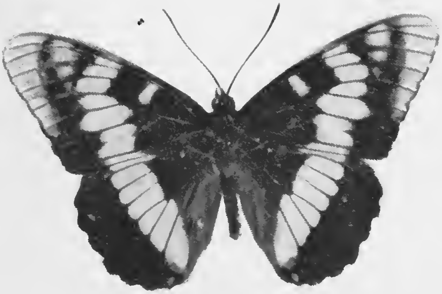
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Flame, Electricity and the Camera

Man's Progress from the First Kindling of Fire to the Wireless Telegraph and the Photography of Color

By George Iles

New York
Doubleday & McClure Co.
1900

TO
JAMES DOUGLAS, LL.D.
OF NEW YORK

CONTENTS

ILLUSTRATIONS

PREFACE

THIS book is an attempt briefly to recite the chief uses of fire, electricity, and photography, bringing the narrative of discovery and invention to the close of 1899. In covering so much ground it has been necessary to choose from a vast array of facts such of them as are fairly representative, laying stress upon those whose proven importance or high promise gives them most prominence in the public mind. Passing to the laws which underlie invention and discovery, this book endeavours to answer the question, Why has the nineteenth century added more to science than all preceding time? It will be found that the latest achievements of man illuminate his path of progress in remarkable fashion, and enable us to discern the promise of the wireless telegraph in the first blaze kindled by a savage, to understand how photography in natural colours has succeeded to the first rude contours drawn by the hand of man. Throughout the volume it is sought, also, to show how profoundly recent accessions to knowledge are transforming the foundations of social, political, and economic life, while, at the same time, they are correcting and broadening the deepest convictions of the human soul.

The author is under obligations first and chiefly to John Fiske, the dean of American evolutionists, who accorded his generous commendation to the draft of this volume which he read in the summer of 1899. Other indebtedness is acknowledged in the course of the book; it is here fitting that grateful thanks should be rendered to the revisers whose names follow, acquitting them of any error which may have entered into the work since its first correction at their hands: Mr. J. C. Abel, editor *Photographic Times*, New York; Mr. F. H. Badger, city electrician, Montreal; Professor F. W. Clarke, chemist to the United States Geological Survey, Washington; Mr. James Douglas, president Copper Queen Company, New York; Professor C. Hanford Henderson, Pratt Institute, Brooklyn, New York; Mr. Walter Hough, United States National Museum, Washington; Mr. Ernest Ingersoll, New York; Mr. W. D. Le Sueur, Ottawa, Canada; Mr. Edward S. Morse, director, Peabody Academy of Science, Salem, Massachusetts; Mr. G. F. C. Smillie, engraver, United States Bureau of Engraving and Printing, Washington; Mr. T. W. Smillie, chief photographer, United States National Museum, Washington; and Mr. Edward William Thomson, Boston, Massachusetts.

The sources of several illustrations are acknowledged as they appear; other obligations are as follows: From the publishers of the *Electrical World and Engineer*, New York (from their Electrotechnical Series, edited by Professor E. J. Houston and Mr. A. E. Kennelly), Figs. 29, 35, 37, 38, 40, 42, 55, and 65; from Dr. David Gill, director Royal Observatory, Cape of Good Hope, Plate XVI; from Mr. Louis Glass, San Francisco, Plate VI; from Mr. N. H. Heft, New Haven, Fig. 53; from Professor James E. Keeler, director Lick Observatory, Mount Hamilton, California, Plate XIX; from Professor S. P. Langley, secretary Smithsonian Institution, Washington, Fig. 47 and Plate XXI; from Professor E. C. Pickering, director Harvard Observatory, Cambridge, Massachusetts, the spectrum of Beta Aurigæ, part of Plate XVII (much reduced) and Plate XVIII; from Mr. T. W. Smillie, chief photographer, United States National Museum, Washington,

Plate VIII (here retouched) and Plates VII and XV; from the Smithsonian Institution, Washington, Figs. 1-6, taken from monographs by Mr. Walter Hough in the series of the United States National Museum; from the United States Bureau of Ethnology, Washington, Figs. 8, 80, and 81.

The author desires to remind the reader that "the multiplication of effects," here illustrated with details drawn from the recent progress of science, forms the theme of a chapter in Herbert Spencer's *First Principles*.

The main argument of this book was indicated by the author in the *Popular Science Monthly*, June, 1876. Professor William Stanley Jevons, author of *The Principles of Science*, said that this preliminary statement contained "many acute and profound suggestions." A second and fuller outline appeared in the *Popular Science Monthly*, June, 1896.

NEW YORK, March, 1900.

CHAPTER I

INTRODUCTORY

A New Supremacy and its Meaning.

WITH the mastery of electricity man enters upon his first real sovereignty of nature. As we hear the whir of the dynamo or listen at the telephone, as we turn the button of an incandescent lamp or travel in an electromobile, we are partakers in a revolution more swift and profound than has ever before been enacted upon earth. Until the nineteenth century fire was justly accounted the most useful and versatile servant of man. To-day electricity is doing all that fire ever did, and doing it better, while it accomplishes uncounted tasks far beyond the reach of flame, however ingeniously applied. We may thus observe under our eyes just such an impetus to human intelligence and power as when fire was first subdued to the purposes of man, with the immense advantage that, whereas the subjugation of fire demanded ages of weary and uncertain experiment, the mastery of electricity is, for the most part, the assured work of the nineteenth century, and, in truth, very largely of its last three decades. The triumphs of the electrician are of absorbing interest in themselves, they bear a higher significance to the student of man as a creature who has gradually come to be what he is. In tracing the new horizons won by electric science and art, a beam of light falls on the long and tortuous paths by which man rose to his supremacy long before the drama of human life had found a singer or a chronicler.

Of the strides taken by humanity on its way to the summit of terrestrial life, there are but four worthy of mention as preparing the way for the victories of the electrician—the attainment of the upright attitude, the intentional kindling of fire, the maturing of emotional cries to articulate speech, and the invention of written symbols for speech. As we examine electricity in its fruitage we shall find that it bears the unfailing mark of every other decisive factor of human advance: its mastery is no mere addition to the resources of the race, but a multiplier of them. The case is not as when an explorer discovers a plant hitherto unknown, such as Indian corn, which takes its place beside rice and wheat as a new food, and so measures a service which ends there. Nor is it as when a prospector comes upon a new metal, such as nickel, with the sole effect of increasing the variety of materials from which a smith may fashion a hammer or a blade. Almost infinitely higher is the benefit wrought when energy in its most useful phase is, for the first time, subjected to the will of man, with dawning knowledge of its unapproachable powers. It begins at once to marry the resources of the mechanic and the chemist, the engineer and the artist, with issue attested by all its own fertility, while its rays reveal province after province undreamed of, and indeed unexisting, before its advent.

Every other primal gift of man rises to a new height at the bidding of the electrician. All the deftness and skill that have followed from the upright attitude, in its creation of the human hand, have been brought to a new edge and a broader range through electric art. Between the uses of flame and electricity have sprung up alliances which have created new wealth for the miner and the metal-worker, the manufacturer and the shipmaster, with new insights for the man of research. Articulate speech borne on electric waves makes itself heard half-way across America, and words reduced to the symbols of symbols—expressed in the perforations of a strip of paper—take flight through a telegraph wire at twenty-fold the pace of speech. Because the latest leap in knowledge and faculty has been won by the electrician, he has widened the scientific outlook vastly more than any explorer who went before. Beyond any predecessor, he began with a better equipment and a larger capital to prove the gainfulness which ever attends the exploiting a supreme agent of discovery.

As we trace a few of the unending interlacements of electrical science and art with other sciences and arts, and study their mutually stimulating effects, we shall be reminded of a series of permutations where the latest of the factors, because latest, multiplies all prior factors in an unexampled degree.[1] We shall find reason to believe that this is not merely a suggestive analogy, but really true as a tendency, not only with regard to man's gains by the conquest of electricity, but also with respect to every other signal victory which has brought him to his present pinnacle of discernment and rule. If this permutative principle in former advances lay undetected, it stands forth clearly in that latest accession to skill and interpretation which has been ushered in by Franklin and Volta, Faraday and Henry.

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[1] Permutations are the various ways in which two or more different things may be arranged in a row, all the things appearing in each row. Permutations are readily illustrated with squares or cubes of different colours, with numbers, or letters.

Permutations of two elements, 1 and 2, are (1 × 2) two; 1, 2; 2, 1; or *a, b; b, a*. Of three elements the permutations are (1 × 2 × 3) six; 1, 2, 3; 1, 3, 2; 2, 1, 3; 2, 3, 1; 3, 1, 2; 3, 2, 1; or *a, b, c; a, c, b; b, a, c; b, c, a; c, a, b; c, b, a*. Of four elements the permutations are (1 × 2 × 3 × 4) twenty-four; of five elements, one hundred and twenty, and so on. A new element or permutator multiplies by an increasing figure all the permutations it finds.

Light as a Limner.

Although of much less moment than the triumphs of the electrician, the discovery of photography ranks second in importance among the scientific feats of the nineteenth century. The camera is an artificial eye with almost every power of the human retina, and with many that are denied to vision—however ingeniously fortified by the lens-maker. A brief outline of photographic history will show a parallel to the permutative impulse so conspicuous in the progress of electricity. At the points where the electrician and the photographer collaborate we shall note achievements such as only the loftiest primal powers may evoke.

Permutative Multiplication a Universal Rule of Progress.

A brief story of what electricity and its necessary precursor, fire, have done and promise to do for civilisation, may have attraction in itself; so, also, may a review, though most cursory, of the work of the camera and all that led up to it: for the provinces here are as wide as art and science, and their bounds comprehend well-nigh the entirety of human exploits. And between the lines of this story we may read another—one which may tell us something of the earliest stumblings in the dawn of human faculty. When we compare man and his next of kin, we find between the two a great gulf, surely the widest betwixt any allied families in nature. Can a being of intellect, conscience, and aspiration have sprung at any time, however remote, from the same stock as the orang and the chimpanzee? Since 1859, when Darwin published his *Origin of Species*, the theory of evolution has become so generally accepted that to-day it is little more assailed than the doctrine of gravitation. And yet, while the average man of intelligence bows to the formula that all which now exists has come from the simplest conceivable state of things,—a universal nebula, if you will,—in his secret soul he makes one exception—himself. That there is a great deal more assent than conviction in the world is a chiding which may come as justly from the teacher's table as from the preacher's pulpit. Now, if we but catch the meaning of man's mastery of electricity, we shall have light upon his earlier steps as a fire-kindler, and as a graver of pictures and symbols on bone and rock. As we thus recede from civilisation to primeval savagery, the process of the making of man may become so clear that the arguments of Darwin shall be received with conviction, and not with silent repulse.

Growth is Slow, Efflorescence is Rapid.

As we proceed to recall, one by one, the salient chapters in the history of fire, and of the arts of depiction that foreran the camera, we shall perceive a truth of high significance. We shall see that, while every new faculty has its roots deep in older powers, and while its growth may have been going on for age after age, yet its flowering may be as the event of a morning. Even as our gardens show us the century-plants, once supposed to bloom only at the end of a hundred years, so history, in the large, exhibits discoveries whose consequences are realised only after the lapse of eons instead of years. The arts of fire were slowly elaborated until man had produced the crucible and the still, through which his labours culminated in metals purified, in acids vastly more corrosive than those of vegetation, in glass and porcelain equally resistant to flame and the electric wave. These were combined in an hour by Volta to build his cell, and in that hour began a new era for human faculty and insight.

It is commonly imagined that the progress of humanity has been at a tolerably uniform pace. Our review of that progress will show that here and there in its course have been *leaps*, as radically new forces have been brought under the dominion of man. We of the electric revolution are sharply marked off from our great-grandfathers, who looked upon the cell of Volta as a curious toy. They, in their turn, were profoundly differenced from the men of the seventeenth century, who had not learned that flame could outvie the horse as a carrier, and grind wheat better than the mill urged by the breeze. And nothing short of an abyss stretches between these men and their remote ancestors, who had not found a way to warm their frosted fingers, or lengthen with lamp or candle the short, dark days of winter.

Throughout the pages of this book there will be some recital of the victories won by the fire-maker, the electrician, the photographer, and many more in the peerage of experiment and research. Underlying the sketch will appear the significant contrast betwixt accessions of minor and of supreme dignity. The finding a new wood, such as that of the yew, means better bows for the archer, stronger handles for the tool-maker; the subjugation of a universal force such as fire, or electricity, stands for the exaltation of power in every field of toil, for the creation of a new earth for the worker, new heavens for the thinker. As a corollary, we shall observe that an increasing width of gap marks off the successive stages of human progress from each other, so that its latest stride is much the longest and most decisive. And it will be further evident that, while every new faculty is of age-long derivation from older powers and ancient aptitudes, it nevertheless comes to the birth in a moment, as it were, and puts a strain of probably fatal severity on those contestants who miss the new gift by however little. We shall, therefore, find that the principle of permutation, here merely indicated, accounts in large measure for three cardinal facts in the history of man: First, his leaps forward; second, the constant accelerations in these leaps; and third, the gap in the record of the tribes which, in the illimitable past, have succumbed as forces of a new edge and sweep have become engaged in the fray.[1]

The interlacements of the arts of fire and of electricity are intimate and pervasive. While many of the uses of flame date back to the dawn of human skill, many more have come to new and higher value within the last hundred years. Fire to-day yields motive power with tenfold the economy of a hundred years ago, and motive power thus derived is the main source of modern electric currents. In metallurgy there has long been an unwitting preparation for the advent of the electrician, and here the services of fire within the nineteenth century have won triumphs upon which the later successes of electricity largely proceed. In producing alloys, and in the singular use of heat to effect its own banishment, novel and radical developments have been recorded within the past decade or two. These, also, make easier and bolder the electrician's tasks. The opening chapters of this book will, therefore, bestow a glance at the principal uses of fire as these have been revealed and applied. This glance will make clear how fire and electricity supplement each other with new and remarkable gains, while in other fields, not less important, electricity is nothing else than a supplanter of the very force which made possible its own discovery and impressment.

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[1] Some years ago I sent an outline of this argument to Herbert Spencer, who replied: "I recognise a novelty and value in your inference that the law implies an increasing width of gap between lower and higher types as evolution advances."

CHAPTER II

FLAME AND ITS FIRST USES

ON that familiar theme, the significance of common things, a word may still be spoken. Nothing is commoner, nothing is more necessary to civilisation, than fire, which was to primitive man a luxury both costly and precarious. There may be both profit and interest in a glance at the steps which join the fire-user of to-day with the fire-user of old. Let us begin at home.

Fire To-day and of Old.

Upon a village near the Hudson, twenty miles from New York, dawn is slowly breaking in early winter. From the moment when a match is struck to boil the tea-kettle until, at the close of the working-day, the evening lamp is extinguished, the dependence of that village on fire is so constant that life can hardly be imagined without it. Were there no fire there could be no soap to wash with, no window-pane to reveal the threat or promise of the morning sky, no rolls nor coffee, neither plate nor cup, no knife and fork for bread and chop. The house itself is born of fire. Its furnace for heating was built of molten iron; its smoke pours into a chimney whose brick, together with the tiles of the hearth, the cement of the cellar, and the plaster of the walls, came out of diverse flaming kilns. Other kilns dried the pine and cedar for the outer walls, the floors and roof; every plank and board was turned out cheaply and quickly by giant saws, all furnace-driven. From smelted ores came the boiler of copper, the water-pipe of lead, the gas-pipe of iron, the bell-wires of steel, with every nail, hook, and rivet for their securing. As with the house, so with its furnishings: its carpets and curtains, as well as the clothing of the family, were made by harnessing a steam-engine for the business, though all might have been manually carded, spun, and woven from the sheep's back and the cotton-boll.

A railroad train for the metropolis is taken, with further indebtedness to fire. Coal glows beneath the engine boiler, while flame has plainly been a factor in all that surrounds the passenger, from car-frame to window-screen, from the telegraph wire through which the train gets orders, to the steel rails upon which it is swiftly borne. The journey ends in a city plainly dependent upon fire at every turn—from the steel building going up by the aid of an oil-engine, to the peddler's tray of enamelled badges, which repeat the reds and blues of the flames that painted them.

These every-day observations might be multiplied indefinitely; they suggest the question, Could man be man without fire? Not his arts of life only, but he himself has come to be what he is through changes, for the larger part gradual, during uncounted ages. If the clock of time could be turned back for millions of years, we should see the progenitors of mankind the brethren of the brute, because fireless as the brute is to-day. In so far as the blurred and scanty story of early man can be pieced together, it tells us that nothing has done more to part man from his lowly kindred than his acquired mastery of flame.

However far back the lineage of man-in-the-making may be traced, we are obliged to think of him as beginning with some decided superiority to his kindred of the forest and the plain. His advantage may have lain in keener sight, in a better faculty of prehension, or in that quickening of the intelligence which has its spring in affection, as in his companion the dog. Whatever the point of departure of man from brute, in nothing could his human quality have been more decisively evinced than in his behaviour toward fire. While other animals looked upon a blaze with idle allurement or stupid fear, he had sense enough to see that some of its work was good; its radiance in wintry air was sunlike and cordial, its half-burned sticks were tools for food-getting, were weapons for battle.

Then, as now, volcanoes were the chief sources of natural fire; next would rank oil-wells, such as those of Baku on the Caspian Sea, which in historic times have flamed or smouldered for generations together. Many minor agencies were less uncommon—a lightning-stroke setting a tree ablaze, a meteorite descending on withered underbrush, a globule of dew or balsam focussing a sunbeam on resinous twigs, a storm driving the stems of a bamboo grove against each other until sheer friction excited flame. At Bavispe, in Mexico, an earthquake in May, 1887, was accompanied by devastating fires; nearly every range of hills in the surrounding country had its trees set ablaze by the sparks from hard stones as they smote against each other in swift descent. The beach-wrecked carcass of a whale, around which dead leaves and straw had gathered, has been known to burst into fire, a type of many a case of spontaneous ignition that offered man the golden gift of flame when he knew but enough to enjoy it with passive wonder. As he would watch a conflagration take its way through a clump of trees or a stretch of dry marsh, he learned much: the flame was here sluggish, there fierce; one bush was consumed as if by lightning, another in dense smoke and slowly; through sun-parched grass and underwoods a blaze would sometimes sweep so fast as to imprison deer and stifle birds—the incidental baked meats not without their hint of cooking. Then came the action which, simple as it is, has never been observed in any mere brute

—the deliberate adding of fuel to fire so as to prolong its benefits. Perhaps this was done in pure playfulness, excited by the enjoyment of seeing the sparkle and hearing the crackle of the flames; but it presently confirmed the observation that the pine burns better than the redwood, that the hickory, beech, and mesquite yield the hottest fire.

The Upright Attitude.

But to what prior advantage was this early man beholden for intelligence already distinctly human? The answer is that for ages his brain had been informed and strengthened by his hand. Yet mechanical skill was no monopoly of his; birds could, with bill and feet, all but manipulate twigs, moss, leaves, and fibre for their nests, or carve out of wood and earth receptacles for their eggs; elephants could tear from trees boughs long enough to wield with their trunks and scratch leeches from their sides; monkeys, rending branches in quest of nuts and fruit, could on occasion throw them as missiles, and had learned to dispose these branches for rude shelter from wind and rain. Here already was the significant heightening of bodily powers by the seizure and use of things outside the body. A stick made the brute's arm longer, a stone made deadly a blow from his fist; in external aids so simple lay the germ of all mechanic art. How was it that man had already become the one developer of that art? Because he had acquired the upright attitude long before the days we are trying to recall. When his upper limbs had become arms and hands, freed from the drudgery of locomotion, his long fingers and opposable thumbs had learned many an aptitude denied the elephant's trunk or the gorilla's paw. And every gain in skill and deftness did its best work in enlarging and clarifying his brain as a thinking instrument.[1]

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[1] Dr. William Munro treats "The Relation between the Erect Posture and the Physical and Intellectual Development of Man," in his *Prehistoric Problems.* W. Blackwood & Sons, Edinburgh and London, 1897.

Observation and Experiment.

If we assume, in retracing the first steps of man, that the thing easiest to do was the thing first done, he began by dashing against a stone whatever he wished to break; then he took from the ground sticks and stones and grasped them for new convenience and effect; afterward, when even the best that he could find were not what he wanted, he passed to the breaking, or biting, or rubbing, or grinding of branches, boulders, pebbles into such shapes as he desired. Whenever he, being near to natural fire, acted on the impulse, born of curiosity and dexterity, to put stick and stone in the flame, at first with the equal hope that both would burn, he crossed another of the bridges over which no brute has ever had the wit to follow him. He passed from the field of mechanics to the higher walk of chemistry. He had long been able to alter the shape of an object; he now gained power to change its substance as well.

He found that the stoutest staffs, held over the fire, soon turned black, lost their strength, and could be shaken to fragments with the slightest blow. He learned that some of the hardest stones, the granites, were split by flame—to this day the quarrymen of southern India part their granite blocks with fire. He discovered that limestones crumbled as they changed their hue to white; that sandstones stood unscathed, however furious the heat that bathed them. It was by such resistance to fire, as well as by its close texture, that soapstone recommended itself to the Eskimos as the material for their lamps. Primitive man observed, too, that the clay or sand on which his fire was oftenest laid remained unconsumed. As his brain grew more perceptive, he noticed that sometimes, where fire had scorched the ground, plants afterward bloomed with rare luxuriance—a useful hint when he came to be a deliberate planter and cultivator of the soil. We may well suppose that one of his first cosmetics was the soot from oily fuel, that the biting quality of water mixed with ashes was remarked early in the day of fire-using. Thus began the art of making many substances rare or quite unknown before, each discovery raising curiosity and dexterity to a new pitch. In the long afternoons of savage leisure, uncounted random observations, or even experiments, served to implant the vague faith in transmutation which later kindled the hopes of alchemy. How strangely were leaf and flower, twig and root, changed in colour and quality at the touch of fire! What was to prevent their returning as mysteriously as they had vanished in a blaze?

The more use and interest man found in fire, the more anxious he became to maintain it as long as he could. Fuel might be scarce; to seek and fetch it long distances might be an arduous enterprise; hence unremitting care was taken to preserve embers under cloaks of sand, or earth, or what not, none of them better than their own ashes well pressed down. Such cloaks were of peculiar value when fire had to be carried from place to place, for they at once protected it from exhaustion and made its carriage safe and easy. When Europeans first touched at the Andaman Islands they found the natives able to preserve fire, but ignorant of how to create it. The arts of maintaining and transporting fire were practised so long, and under so grievous penalty, that we find flame faithfully perpetuated on the altars of religion to this day. The Damaras and Andamanese still guard their tribal blaze in communal huts, as the Romans did in their temples two thousand years ago.

As primitive man ate in the warmth of his fire, he would sometimes throw into it bones, or the surplus fat of birds, beasts, or fish, and so become acquainted with a fiercer fuel than wood, one melting at times into oil, which he saw burning with much light. To burn fat by itself would mark a further stage of discovery, and so came the first lamp, such as flares to-night in the cabins of the Tennessee mountains. From deliberately using fat and its oil for fuel, there would be an easy transition to trying how other oil-like things would burn. In many places petroleum oozed to the surface of ponds and creeks, proffering fuel by the use of which man's ideas would again be enlarged. Familiar with the fact that some things would give out heat and light, he would, in lack of such things, or from sheer curiosity, try the effect of setting fire to any new substance he might find. And so, in the range of his attempts, he found that peat, lignite, and coal from seams appearing on the surface of the ground, could be added to his store of fuels; and in the procuring of all these he would make and use new tools—with further expansion of his intelligence. Thus clearly did fire endow early man with faculties and facilities for tasks impossible before; bestow upon him the beginnings of comfort and cheer; enable him to set out so fast, to separate, finally, so far from his cousinry of the glade and thicket, that, until Darwin lifted the veil, their family tie lay unrevealed.

Fire Kindled Artificially.

In all the early enjoyment of flame, fear was mingled. A gust of wind, a sudden shower, could put the blaze to flight, and the log, or coal, or peat, however faithfully tended, would sink at last to ashes. With keen intelligence, indebted to the lessons of fire, a man may be imagined saying to himself, in some region of frosty winters: "What if I could summon fire when I chose, instead of trying with such pains to keep it alive? When flame goes out, does it not go somewhere whence I may recall it?" How the wistful question prompted its answer is clear. In rubbing or grinding a bit of wood into shape for tool or weapon it grew warm to the man's touch; when his hand was heavy and quick, the dull heat of friction began to pass into something higher; still he persisted, now in wondrous hope, and saw the scorching and burning wood burst into flame. The blaze, tiny and shrinking as it was, had doubtless often shown itself before, but this time it was aroused by a savage with wit enough to feed it with crumbled moss or broken bark, and repeat its weird creation. When, as in the modern practice, a stick was swiftly turned in a slot, under steady pressure, a tiny cone of dust would slowly gather, smoulder for a few moments, and then spring into a blaze (Fig. 1).

Fig. 1.

Making fire. Hupa Indians, California. U. S. National Museum.

Stones as well as sticks were part of the stock in trade of primitive man, and much pains did he lavish on his flint knives and arrows. The modern Eskimo, almost destitute of wood and metal, works wonders with the bone, the hide, and the sinews of the seal; so with the men of the stone age, their ingenuity in shaping their axes, hammers, and chisels is fairly astonishing. Nor was ornament neglected. Professor Petrie has discovered in Egypt ancient implements worthy to be credited to a primitive jeweller, so delicate is their decoration. Flint is found in many widely scattered chalk-beds. In striking one piece of it upon another to shape the edge of a weapon or a tool, the stone shot out sparks, just as an old-fashioned strike-a-light does now (Fig. 2). At a moment memorable in human fortunes, some of these sparks fell upon dried leaves, sun-cracked pith, or some such fluffy combustible as a cotton-boll or the catkin of an arctic willow. A blaze was born, as many another had been born before; but this time, as with the twin flame from wood, it caught the eye of a man capable of that faithful imitation of nature in which rests the mastery of her. To this hour the spark from flint shares with the flame from wood the whole field of winning fire by primitive means. No piecemeal acquisition this, like learning to hit a mark with stone or bolt. The dexterity which led up to fire-making may have been gained by a succession of minute steps, each separated from the next by a difference scarcely perceptible; but when dexterity rose to the height of kindling a blaze, it opened on that instant a door to a whole universe of power beyond the reach of the hand of man, however skilled, if fireless.

Fig. 2.
Strike-a-light in Use. U. S. National Museum.

The First Lessons of Kindled Fire.

As fire passed from its various birthplaces to one new zone of the world after another, manifold trials disclosed which woods were easiest to kindle. The cottonwood in its crumbling fibre proved the best; the yew, afterward adopted for the bow, was an excellent fire-bringer; in what are now the Southwestern States of the Union, the stalk of yucca and agave were employed with equal success. The dried root of the cottonwood is used to this day by the Moqui Indians because even better than its stem. As tinder for the fleeting spark from flint, dried fungi and frayed bark of many shrubs and trees approved themselves, every region rewarding the seeker with its peculiar supply, generally abundant. In this service the touchwood earned its name; the cones of larch and pine, when slightly charred, were efficient in an uncommon degree.

In the use of all these aids there was wide diversity of skill. Fire-getting by the friction of wood to this day costs the Ainos more than two hours' severe labor. In other tribes this drudgery was long ago abridged by borrowing a tool from a sister art. A common task for the primitive artisan was boring holes in wood, or stone, or shell, with sharp flints whose tapering contour foretold both awl and chisel. By and by these rude perforators were improved in form, and turned with thongs and sinews; through point thus meeting point instead of rambling over an extended surface, the heat was heightened and flame quickly won. The drill, in its first estate but an auger, has gone round the world an effective fire-maker as well (Fig. 3). Its wielder need undertake no search for special kinds of wood, nor is it necessary that his wood be dry; indeed, Zuñi priests, to do their gods the more honour, were wont to moisten the tree whence they drew the sacrificial blaze. Some savage tribes familiar with the fire-drill seldom use it; the Apaches

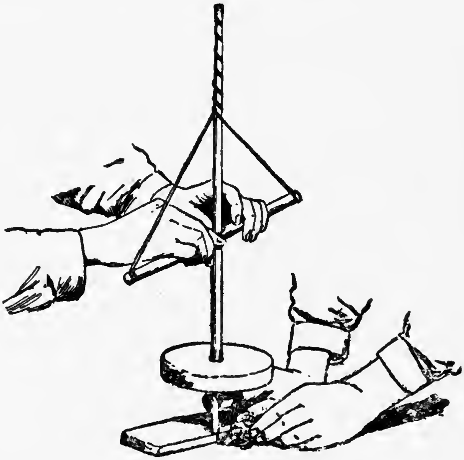

Fig. 3

Iroquois pump-drill for making fire. Onondaga Indians, Canada. U. S. National Museum.

have so much knack in twirling two simple sticks as to educe fire in but eight seconds.

Fire-kindling by Modern Savages.

Nature in showering hints upon inventors has not neglected the fire-maker. A suggestion for an original mode of fire-making may have lain in watching bamboo stems driven against each other in a storm until flame issued from their rasping friction. In the Malay Archipelago, says Alfred Russel Wallace, two pieces of stem are used to kindle fire; a sharp-edged piece like a knife is rubbed across a convex piece in which a notch is cut, nearly severing the bamboo; after sawing across for a while, the wood is pierced, and the heated particles fall below and ignite (Fig. 4). The Ternate Malays and the Tungaras of British North Borneo have improved upon this by striking a piece of china and a bit of tinder against the outside of a piece of bamboo, whose silicious covering yields a spark. The Pacific Islanders and the Negritos of New Britain make fire on yet another plan—by ploughing. They rub a sharpened piece of hard stick against the inside of a bit of dried split bamboo. This produces a

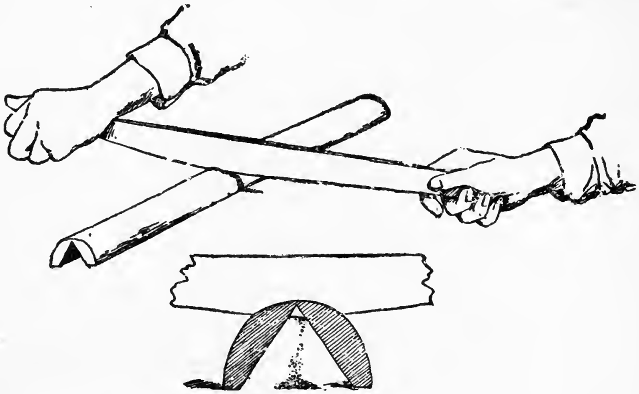

FIG. 4.

Fire-making by sawing. Burmese and Malay method.

fine dust which soon ignites. The flame is fed with grass. Thus everywhere has acquaintance with the uses of fire set man to inventing means of creating it, while the process of invention has made him familiar with new materials and expedients, all with the effect of enlarging his knowledge, of promoting the strength and flexibility of his mind.

From its quickness and convenience the flint method of fire-making had only to be discovered, or borrowed, to supersede at once the friction-stick or the drill. With the conservatism characteristic of religion, the older plan still lingers at the altar. Professor Romeyn Hitchcock says (*United States National Museum Report*, 1887–88, p. 552):

> The fire-drill is used at the festivals of the Oyashiro to produce fire for use in cooking the food offered to the gods. Until the temple was examined officially in 1872, the head priest used it for preparing his private meals at all times. Since then it has been used only at festivals and in the head priest's house on the eve of festivals, when he purifies himself for their celebration in the *Imbidous*, or room for preparing holy fire, where he makes the fire and prepares the food.

Among the Sacs and Foxes, the juniors resort to the white man's matches, the seniors light their pipes with flint and steel (Fig. 5), while the priests still use the bow-drill. The Roman Catholic Church, in its blessing of the new fire on Easter even, carries us back yet farther than to the bow-drill. The officiating priest is required to strike the spark from a stone.

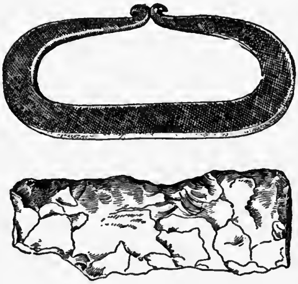

FIG. 5.
Flint and steel. Otoe Indians.
Kansas and Nebraska.
U. S. National Museum.

A long and weary path, with many a twist and turning, stretches between the men who first lighted a fire with flint or friction-stick and the men of to-day who strike the cheap phosphorus match—perfected as recently as 1840. The later steps in that path have been taken through finding substances more and more combustible—first of all, the lighter and more resinous woods; then, sulphur; and last of all, phosphorus. The shred of pine in the friction-match remains as a relic of the fire-stick of the cave-dwellers; it recalls the day when our lowly ancestors first dared to mimic the sun in an artificial beam of warmth and light. And there is more than the match-stick at hand to remind us, in the midst of gas-jets and electric lamps, how the first gropings to both were assured. In the English village of Brandon, on the Little Ouse, thirty miles from Cambridge, flints are still being made by knappers of an expertness such as comes only by inheritance—in this case, from immemorial times. Many of the flints are still struck off in forms closely resembling those of the early stone age.[1]

A Pace Quickened to a Leap.

A century ago Cuvier and his school gave classic form to the catastrophic view of nature; they traced in the world of fossil remains abrupt entrances and exits; in many strata of the globe, whether fossil-bearing or not, they saw the work of earthquake and volcano. What inference better warranted, at that time of comparatively little knowledge, than that species had been created as if by instantaneous fiat? From this view many naturalists of to-day have recoiled so far that they never tire of repeating that nature knows no leaps, no sudden changes.

But let us recall the day when the sea first washed its way across the ridge that ran from Africa to Gibraltar. The preparation for that momentous day, the slow encroachment of the Mediterranean on this strip of land, had occu-

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[1] Mr. William Carter, a flint-maker at Brandon, writes (May 6, 1899): "There are now eighteen flint-makers at work here, each of whom makes two thousand flints a day. The markets are scattered throughout Africa, China, India, Afghanistan, Persia, Russia, Turkey, Norway, and Sweden, where the flints are used chiefly for guns. In Spain they are mainly wanted for strike-lights."

pied ages. In all probability, the rising of a storm of uncommon violence in a few minutes broke down the subsiding barrier at its weakest point. Then speedily followed consequences of life and death to myriads of creatures; uncounted species of molluscs and fish were able to find new prey, while their victims were attacked by new foes too formidable to be resisted. As the gap between shore and shore grew broader, it yawned at last too widely for even the most daring swimmers; carnivorous beasts, thus shut in to either Europe or Africa, were exposed to unwonted stresses, while their maraudings, now limited, left their former prey on the opposite coast less harried and insecure.

The volcano, much more thoroughly studied now than in Cuvier's day, has the same teaching as the sea; the Sandwich Islands may stand as a type of its creations. For ages a huge caldron beneath the Pacific was busy pushing up its cubic leagues of rock and earth. One moment this mass was below the wave, the next it had emerged to air and sunshine. Now birds and insects began to alight upon it; spores and seeds conveyed by them could give birth to ferns, shrubs, and trees; possibilities of life entirely new arrived with its simple lift from the deep. The life histories of both insects and birds confirm the view that the pace of progress may on occasion hasten to a leap. Let us note what follows as soon as insects begin to supplant the winds at the business of fertilising flowers. Flies and moths come to a blossom, attracted by its nectar; their surfaces while they feed are brushed by pollen; away they sail to other flowers and tie a marriage knot with a directness and efficacy denied to the aimless air. Thus, simply through having exteriors which easily catch dust, insects of the narrowest intelligence unknowingly become the painters, sculptors, and perfumers of unnumbered varieties of blossoms. A revolution not less remarkable was wrought when birds first appeared upon earth. In all likelihood it was in perfecting the feathered wing that their emergence from reptilian stock took place. Even the beginnings of flight, accompanied by the heat-retaining raiment of feathers, would have decisive value. The realm of the air with its possibilities of escape from enemies, its new sources of food, its new breadths of climate, stretched itself before the incipient bird. In the struggle for life the developing faculty of flight was the resource more vital than any other, and therefore the power most likely to survive in every favouring variation, with the effect of shortening the period of transition to the new kingdom.

Not less significant are the "sports" of the botanist, of the breeder of sheep and cattle. The Concord grape, seized upon for its excellence by Mr. Ephraim W. Bull; the ancon sheep, so short-legged that fences could be safely lowered; the hornless bull of Paraguay, so much more tractable than his sire, all appeared abruptly from ordinary stock, and transmitted their characteristics as fully as do common fruits, sheep, and cattle. The truth seems to be that nature for long periods and wide areas may move with slow and steady pace, as if gathering her strength and catching her breath; then, as in the twinkling that divides cloud from snow, or a drop of water from its gaseous elements, the micrometer method ceases to apply, change in degree becomes exalted into a change of kind, and gestation yields a life so different from the parent form as to seem a new creation.

Man possessing only such fire as nature gave him, and man creating a blaze at will, are separated by all the distance between mere warmth and vivid flame, between mechanics alone and mechanics plus chemistry. Those heroes of invention, whoever they were, who first kindled flame, did more for human weal than any of their successors in the hierarchy of creative power, for it was their triumph that made possible every other. As we shall see when we come to consider the subjugation of electricity, it has illustrated once again this swift maturing of an accession to the supreme resources of man. Dexterity in one decisive epoch flowered into the mastery of fire; the fruitage of fire made possible the harnessing within a single century a force as weighty as itself with benefits for mankind.

CHAPTER III

THE FIRST GAINS FROM KINDLED FLAME

New Horizons for the Fire-maker.

INCALCULABLE were the gains that began to flow in upon the first fire-maker, his victory won, its spoils assured. Beneath his tread the globe expanded itself with invitation, for now no longer chained by the sunbeam, he added all the frozen North to his hunting-ground. The Eskimos, according to Professor Dawkins, are the lineal descendants of the cavemen. They are the only American aborigines who have invented a lamp; that simple device has enabled them to conquer and hold an outpost twenty degrees nearer the pole than any other human settlement (Fig. 6). Whether the first explorers had caves to fall back upon or not, fire was indispensable to them. A burning brand cleared their paths through forests otherwise impenetrable. When they singled out a tree for their rude carpentry, it was no longer cut down by flints so soon dulled and broken in the process. Fire cunningly applied, to be as cunningly quenched with wet mud, had a sharper and quicker tooth

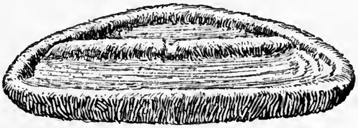

Fig. 6.
Eskimo lamp from Mackenzie River.
U. S. National Museum.

than stone. The tree felled, its trunk was softened and shaped, again by fire, into a canoe for voyages too daring for any raft.

Yet worthier service lay in lifting the dreary pall of night. Until the savage could command fire the clouded evening sky left him as if sightless for toil, for sport, for escape from ravening beasts and sudden tempests. If his feet found a beaten path, it was easy to stray from it in darkness, perchance to pay the penalty with his life. His lowly hearth, heaped with crackling boughs, cheered even more with its light than with its warmth. It drew to its rays the industries of flint and needle; its fitful beam created man's first home. What artificial light means as an educator we can see in a modern instance. The French Canadian habitant forty years ago had nothing better than a flickering, malodorous grease-bowl, which hung over his table from a notched stick. To-day he has a lamp of kerosene, cheap and brilliant, with its invitation to reading and study.

From the moment when fire first glowed within the walls of a dwelling, however lowly, it began to exert an influence upon architecture which persists to the present hour. Let a Western mining village be swept by flames, and although its shanties date back only a few months, their chimneys stand unhurt to say, " Build all as soundly as you build us." Fire makes demands for permanence and solidity which are disregarded at the occupier's peril, at the nation's loss. Fire in ancient times had a dignifying effect on the buildings designed to guard the communal flame at which any one might light his brand and take it home. These central and labour-saving fires, as years went by, took on religious associations. It is plausibly argued that as home is chiefly the creation of fire, so also is the rearing of temples for worship, such as those of Vesta in old Rome, or of the modern Parsees in Bombay.

Thus did flame requite its maker by multiplying his opportunities as an explorer, by broadening the zones in which he might choose a dwelling-place, by giving him security and comfort, and by so eliciting his skill that that larger outer garment—a house—might begin to be rudely fashioned from its prototypes, the cavern and the tree. Fire meant more space to live in, more time to work and play in, and better shelter; it also stood for more and better food. The spoils of the hunter or the fisherman broiled or roasted became more digestible, or, as pemmican, could be longer stored to abridge the see-saw betwixt plenty and want. When it was remarked how readily hot stones imparted their heat to water, the further art of cooking by boiling was approached. To this day the Assiniboines, or stone-boilers, of the Canadian Northwest practise the most ancient known method of seething. They dig a hole in the earth, line it with hide, and fill this with water and meat; hot stones one after another are immersed in the liquid until it mounts to a cooking temperature. From a caldron as crude as this sprang the kettle hollowed from a tree or a soft stone, the basket-kettles of closely twisted fibre common among many Indian and African tribes, wherein water is brought to boiling-heat by the immersion of hot stones.

Cooking.

Having become an adept in this new art, the wife, not less adventurous in experiment than her husband, varied their repasts, an important matter in savage life when dependence upon a single kind of food might mean starvation. She found that plants repulsive in taste, or even poisonous, when plucked from the field, needed only boiling to furnish a wholesome and toothsome dish. The squaws of southern California gather several kinds of cruciferous plants, throw them into hot water, then rinse them out in a stream and use them as food. This boiling and rinsing remove juices which have a bitter taste and provoke nausea. A New Zealand woman, with a degree of temerity hardly to be commended, once ate berries of the *Laurus tawa* after boiling them; she found that the fruit had lost its deadly poison in the kettle. Thus unknowingly did she cross the frontier that divides skill culinary from art medicinal, a feat in which sisters of hers throughout the world have long emulated her example. Primitive broth-pots, wretched and wasteful as they seem to us now, are nevertheless distinguished in their progeny; they foreran the stupendous boilers and digesters of modern industry, the vast metal chambers which pour out sulphuric and nitric acids for the chemist and the electrician. Volta, disposing his crown of cups with its corrosive bath, was a debtor to the savage who first added a kettle to a grill.

Pottery.

From those poor hearths of old sprang many of the arts which most dignify mankind, each in turn as fecund as its parent. The slab on which was laid the broiling fish or fowl became the corner-stone for forge and furnace. Cellini moulding his "Perseus and Medusa" of bronze, Bessemer burning out carbon from his iron that steel should be left behind, both enjoyed inheritance from the savage who first laid a stone before his fire to make its heat more serviceable. In those days of small things it would have seemed absurd to prophesy that fire should yet make artificial stone, and in forms most various, all able to resist flame itself. And yet what else is pottery? So various have been the earths, salts, and metals which have served the potter, so much ingenuity has he displayed in shaping his wares, so much have they called forth all his skill as a decorator and depicter, that the art of the potter fills one of the most interesting chapters in human advance, and is, indeed, wont to mark an era in the chronicles of archæology.

For a product so manifold in its kinds as pottery, so widely diffused throughout the world, it is probable that there were many origins. One of them may have lain in noticing that when a hearth had cooled down on clayey soil the ground had taken on a useful hardness. Or it may be that clay, adhering to boughs or roots as they were thrown upon a fire, gave the same priceless hint. Again, it may have been in coating a stick with clay and thrusting it into a blaze that the first step toward pottery was taken. The second step must have been the discovery of tempering—that a little sand mixed with clay kept the mass from cracking apart. We should remember that in making their baskets impervious to water, the early craftsmen were taking a long stride toward the skill of the potter. To this day, in Arizona the Indians coat their baskets with clay and mud to retain liquids. An ingenious theory as to the beginnings of pottery was published a hundred years ago by M. Goquet. Aware that clay is often daubed on wooden pots and kettles as a protection against flame, he held that when at last the wood was burned off, the clay covering would stand out as a capital vessel by itself. It may have been in some such rude way as this that the industries which now flourish at Sèvres and Worcester first took their rise; and not these only. From primitive wattle and daub probably came the art of making bricks and tiles, scarcely less useful and beautiful than pottery. Clay is so excellent a material for tablets, it is so easily hardened in the fire after it has been impressed by the stylus or the brush, that both in Assyria and Greece it gives us imperishable records of great civilisations.

From vessels which could be trusted on the fire, lessons of the highest value began to be learned. Water is often so scarce to the savage that his wanderings are limited to tracts where he may readily find it. We may surmise that in times of drought sea-water was, in uncounted cases,

Aboriginal Chemistry and Engineering.

boiled in the attempt to make it drinkable. But the longer the boiling the saltier the residue, until at last salt alone remained in the pot. Fire had refused to do the work required of it, but, instead, it had done something better. In a few hours it had produced precious salt, a task for which the sun and wind upon the marshes required weeks. But in the first place water had been joined to the salt, and whither had it fled in the boiling? A cold stick or stone held above the piping pot at once brought to view what otherwise seemed annihilated wholly; and it was further noticed that this recovered water was free from salt—was pure. A trivial enough experiment, perhaps, but it was the starting-point for such great contrivances as the retort, the alembic, and the still, those producers of the acids, alcohols, oils, and gases of modern industry.

A notable addition to the pot or kettle was the lid; it kept in the heat, it kept out falling leaves and flying cinders. When an abrupt access of heat lifted this lid there was a demand for employment by force out of work which, repeated often enough, issued at length in Hero's device of the æolipile, so ingeniously brought down to date in the steam-turbine of the Hon. C. A. Parsons (Fig. 7). The savage, without being able to philosophise about it, had long with flint and fire-stick converted work into heat; it required many a toilsome century to reverse the process and oblige heat to do mechanical work. When the lesson was learned at last, the steam-engineer was glad to profit

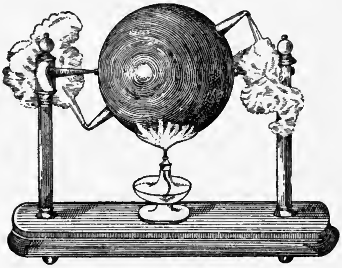

FIG. 7.
Hero's æolipile.

by the knowledge of fuels, of furnace-building, of substances that convey heat well or ill, that fire-users began to gather long prior to any art of writing. Of those distant days we have but the unintended records of forsaken hearths, of rusty tools, of heaps of potsherds—relics eloquent of the mountainous debt the present owes the past.

Glass-making.

As epoch-making as the birth of pottery was the union of luck and skill—the luck earned by the skill—which founded the art of glass-making. Amethysts, emeralds, garnets, and other gems must have been prized from their first finding, as much for their transparency as for their hue and sparkle. In volcanic streams, then as now, there frequently lay masses of obsidian, some of it fairly transparent, and readily broken into thin flakes having a razor-like edge adapted for spears and arrows. When, in the sheer riot of experiment, sand and soda were fused in a blaze which mimicked a volcano's heat, by a man shrewd enough to repeat the act, there was added to human resources a substance of more than golden value. Who shall compute the worth of glass for windows, lanterns, lamps, and spectacles? In the telescope and microscope it reveals worlds too remote or too minute for the unassisted eye; in the lenses of the camera, as we shall presently remark, we obtain a secondary and derived vision of every image, be it luminous or not, that wings its way through space. One of the first services of glass in the electric age was to form the Leyden jar and the plates from which frictional electricity streamed forth. For the later developments of electric art, the conveyance of currents for the telegraph and for power, glass and its next of kin, porcelain, have been invoked for indispensable aid as insulators.

Fire to early man had many minor uses, each important in its way. As hunter and fisherman he employed it to lure his prey, to affright beasts to which he himself was

Lures.

prey, or to yield a protecting veil of smoke against insect pests scarcely less to be dreaded. Ernest Ingersoll says: "When a savage built a blaze in front of his rock shelter it would form an efficient guard from attacks by wild beasts; within a circle of fires a camp of hunters might securely rest or sleep. When the camp was left behind a fire-brand would be one of the best of weapons, for, when sturdily wielded, no animal is able to face it. To this day, the flourishing of fire-brands as a defence against dangerous animals is common among wild men and hunters encamped in savage regions. The ability to set fire to the jungle might more rarely be of great service in ridding the locality of troublesome brutes. Some quadrupeds, at once timid and curious, deer especially, are allured by a light, just as are many familiar moths and flies of summer. Deer feed and wander mainly at night, or just before dawn, and seldom at any other time visit ponds, streams, or water-holes of the plains. The hunter who carried a little fire in the bow of his canoe, and kept himself wholly out of view, could easily paddle within arrow-shot or spear-fling of a deer or antelope, which would stand surprised out of its natural caution by the strangeness of the floating light. This resource of the hunter is so widely practised by existing savage races that it probably dates back very far in the history of primitive food-getting. As with hunting, so with fishing, in both modern and remote times. A bright light now serves a double purpose, and may have done so long ago. The flare brings to view the bottom of the stream, or of the sea at ebb-tide, so that the fisherman, as he floats quietly by, or as he stands upon a steep bank or isolated rock, can see to strike at fish whose activity is for the most part nocturnal. Moreover, to some fishes, and especially to the sturgeon, such a light is an irresistible attraction."

Diverse Aid.

Half-burnt sticks from their first tests had formed tough and durable weapons, oftener in demand than the firebrands, their original form. Of alliance to the fire-brand there was, in later days, a weapon much more terrible. When the first colonists came from Europe to America, the Indians attacked them with a firearm, where invented nobody can tell. This weapon was an arrow to which flaming tow was fastened, so as to ignite the wooden houses of the settlers. That this strange device may have been contrived long before seems probable when we learn from Alcedo that the Caribs had a similar weapon. So peculiar an invention is likely to have sprung from a single mind, and, if so, must have required ages to find its way to New England.

The man of war has often taught a lesson to the man of peace. Heavy sticks hardened in fire and drawn over the soil, or dragged through it, as in China, were the forerunners of the harrows and ploughs of later agriculture. Fire softened the resins, gums, and bitumens which cemented and adorned primitive boats and tools, such as the Eskimos still make. Even the somewhat advanced art of annealing was long ago a familiar practice. Obsidian buried under embers and allowed to cool with them became less brittle for the stress and strain of battle or the chase.

Fire can preserve as well as destroy. Many ancient builders, those of Switzerland in particular, underpinned their lake-dwellings with stakes so well charred that they have withstood insects and decay for thousands of years. At Robenhausen, where excavations have been conducted with thoroughness and care, one may see relics of tools, bows, and even a last, of wood. It would seem that during recurrent conflagrations, garments of woven cloth, bits of dressed leather, and fragments of mills and looms fell into the water as the scaffolding gave way, sank into the mud of the lake, and, because well charred, have remained unchanged to the present day. At the National Museum in Naples are many relics of Pompeii as overwhelmed by Vesuvius in A. D. 79; among these are olives, figs, grain, and bread, which fire reduced to unalterable form more than eighteen centuries ago.

Fire, from remote times, has been employed to give signals, as a means of communicating intelligence. In the early days of man as a mariner he erected on storm-swept coasts beacons whose blaze, faithfully tended, gave warning or comfort to drifting voyagers, the flickering ray foretelling the sunlike beam of Sandy Hook or Skerryvore. As warrior he crowned the highest hills with conspicuous flares to voice alarm to scattered allies, prefiguring every modern telegraph. The smoke of camps, in its betraying or reassuring wreath, rises higher than fire, and this has been fruitfully observed by savages on opposite sides of the planet. The Indians of the plains, as described by Custer, resort to the loftiest hills for their signal-stations. There they build fires, and by placing an armful of partly green grass or weeds over the blaze as if to smother it, a dense white smoke is created, which may ascend in a calm atmosphere as a column for hundreds of feet. A current of smoke established, the Indian spreads a blanket over the smouldering mass so as to confine the smoke for a few moments. By rapidly removing the blanket he sets the column free, and thus by a succession of cloud-pulses he sends up a message which may be discerned as far as fifty miles away. The aborigines of Victoria, Australia, have a like code of smoke-signals by which they have been observed to tell their distant comrades of the capture of a whale or the advent of an exploring party.

A Primitive Telegraph.

Thus even in its aboriginal uses fire in a high degree multiplied the resources and powers of man. Its heat procured him a rich array of benefits: it unbarred a new breadth of the globe as he wandered forth in search of better dwelling-places; it enlarged a dietary which became the while more wholesome and appetising; it gave him the wherewithal to become a potter and glass-maker. The light which streamed from his blaze was as generous in blessings: it made night as day; it rendered habitable and even cheery the caves which otherwise were dark and perilous dungeons; it served to lure the fish and game upon which he subsisted; it was a means of communicating intelligence as far as the eye could see a bonfire or a pillar of smoke.

CHAPTER IV

THE MASTERY OF METALS

The Finding of Copper.

IN the fullness of time the fire-user came to a discovery destined to throw all the minor utilities of flame into eclipse—a discovery, indeed, only second in dignity to that of fire-kindling itself. On the shores of Lake Superior, in the Connecticut Valley, and in many other parts of the world, were picked up for their promise of new qualities certain heavy stones—nothing else than native copper. These masses, treated as if they were ordinary stones like the rest, soon displayed properties of a marvellous kind. Other stones were easily chipped and broken under the hammer; these spread themselves out until they were thin enough to be used as knives and chisels, having an edge much more lasting than that of flint. More singular still, when this red substance was put in the fire, it softened so as to yield to the hammer more freely than before; if left still longer in a blaze it melted and ran like so much beeswax.

Here all at once was discovered a new kind of wealth, almost as on the memorable day when flame was first intentionally created. Never yet has man, early or late, come into new riches without thinking of new investments; very soon copper was shaped into a wide variety of articles, their forms borrowed from the knives, chisels, and ornaments of familiar stone. The metal, however, was scarce, and stone plentiful, so that as a material for tools and weapons stone long retained its predominance; it was as paving the way to the great achievements of metal-working that copper was first important. Fire in the hands of the metal-worker has proved itself a multiplier of gifts, a creator of powers not less remarkable than in other provinces of its rule.

Copper fortunately occurs not only in masses substantially pure, but also in carbonates which yield the metal at comparatively low temperatures. Mr. James Douglas observes that the Indians of Arizona have long used as food the unopened interior leaves of the *Agave palmeri*, or mescal, after baking them in hot, stone-lined pits without access to air. These pits would readily come to a temperature high enough to reduce copper from pieces of carbonate ore common in the region, which might be built into the walls of the pits. The accidental discovery of this reduction would lead to the practice of copper-smelting.[1]

Another metal, discovered probably as early as copper, and, fortunately, in its easily reducible oxide, tinstone, was tin. Whether at first copper and tin were found combined in an ore, or whether their union came about through random experiment, nobody can say. Tin, poor in itself, when joined to copper to form bronze, develops qualities more desirable than those of copper alone, tin having the dormant kind of value that comes out only in a partnership. When metals fuse together they dissolve each other in ways as yet little understood. The solutions which, when cooled to solidity, are called alloys, are riddles as yet unread, like many of the kindred solutions which remain liquid at ordinary temperatures.[2] Bronze is tougher,

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[1] *Mineral Industry*, Vol. III, p. 243.

[2] Sir William Roberts-Austen has for years conducted a series of researches on the properties of alloys. A remarkable result has followed his applying a

stronger, more elastic than copper; it takes a sharper edge and keeps it longer; it can be poured into moulds at a lower temperature, to come forth a casting fairly true in form; and, what is a matter of moment, all these qualities are modified as the proportions of copper and tin are varied. Offering this fund of excellence, bronze gave the art of war an impulse almost as decisive as that due to gunpowder when, in the fourteenth century, it enabled the soldiers of Europe to throw away the crossbow.

The Metals in War.

At the Conquest by William the Norman, in the eleventh century, his army and that of Britain, in point of bravery, were equal; but the soldiers of William had an inestimable advantage in the proficiency of their smiths. The Normans bore weapons of steel incomparably elastic and strong; they were clad in steel armour from head to foot; their horses were shod with iron shoes. What chance had the Britons, lacking as they did this aid from the miner and the craftsman? In prehistoric times it is altogether likely that when the lance or sword of copper or bronze first clashed against the cudgel of stone, it won victories even more decisive against tribes or races not intelligent or fortunate enough to rise to the use of the new arms. When, in turn, iron and steel were opposed to bronze, there was a repetition of the tragedy by which warriors who fell short of a new acquisition were not simply vanquished, but, in all likelihood, extirpated—for in savage warfare no mercy was shown to the conquered.

Here we have a probable explanation of the gaps which appear in the genealogical trees of many native races. The appropriation for the first time of metals as arms, the successive improvements in the treatment of these metals,

moderate heat in his experiments. On fusing a strip of gold to the base of a lead bar, maintained for a month at 250° C., well below the melting-point of lead, the gold-lead alloy has travelled up to the top of the lead bar, a distance of $2\frac{3}{4}$ inches. This phenomenon is plainly akin to that of liquid diffusion.

meant making weapons of sharper edge and greater strength. This would conduce to the obliteration of tribes or even races equipped from the forest or the quarry instead of the mine, or wielding arms of bronze against arms of steel. Metals as tools meant much; as weapons they meant everything. In the corn-field, the workshop, and the home the mastery of metals taught a new deftness, bestowed a new opulence; in the field of war the skill of the sword-maker and the armourer stood for victory and life as against defeat and extinction. When the archer was swept away by the gunner, it was because skill had made for gunpowder a metal barrel strong enough to resist extreme pressures.

Metal Tools.

For tools no less than for weapons, bronze is almost as much to be preferred to copper as copper is preferable to simple stone. Especially have axes of bronze played a leading part in the prelude to civilisation. Forests fell before them which would have forever defied brittle axes of stone—forests which could not have been safely attacked with the firebrand. Professor Dawkins, in *Early Man in Britain*, says: "Under the edge of the bronze axe clearings would be rapidly produced, pasture and arable land would begin to spread over the surface of the country. With the disappearance of the forest wild animals would become scarce, hunting would cease to be so important, agriculture would improve, and a higher civilisation inevitably follow." Bronze sickles found in Great Britain, and more abundantly in Switzerland and Savoy, testify that the alloy was early impressed into the service of husbandry.

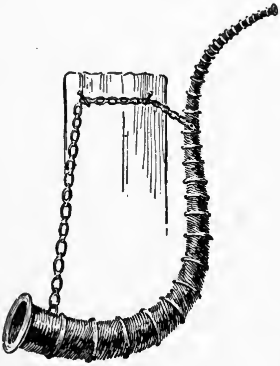

FIG. 8.

Primitive bronze horn, Sweden. U. S. National Museum.

In its Egyptian varieties bronze is as hard as steel, furnishing tools almost indestructible. From its beauty the compound metal gave opportunity to decorative as well as to useful art. Ancient horns and bracelets of bronze would do credit to modern workshops (Fig. 8). Why, it may be asked, have comparatively so few objects in copper been transmitted to us from the long interval between the age of stone and the age of bronze? The probable explanation is that most articles of copper were sent to the melting-pot as soon as the better qualities of bronze were understood.

Iron.

But as bronze had displaced copper, so it in turn was to meet a supplanter. How or when iron was discovered it is idle to conjecture. From its comparative purity in meteorites it is thought that they were the earliest sources of it; to this day the Eskimos derive their iron from meteoric masses. Nickel, often borne in meteorites, has been detected in many ancient articles of iron. In the Mesabi Range of Lake Superior, iron ore is torn from the hills much as if it were the material for common macadam; in many other quarters of the world it is almost as plentiful. With fireplaces taking on somewhat the shape and character of furnaces, with fuels better chosen, with hollow reeds or fans to blow an artificial breeze, it was inevitable that one day ironstone should be thrown into a flame hot enough to free the iron from its ore. In Africa easily reduced ores are still worked by the simplest means; Africa, indeed, from its wealth in such ores, may well have been the scene of the first iron-working.

The new metal soon proved itself worth all the trouble of its production. It was stronger than bronze, more elastic, and in the form of steel took a keener edge. When heated to whiteness two pieces could easily be welded with the hammer, so that long rods or lances could be made from it. What was decisive in the matter, however, was the profusion of ironstone in contrast with the rarity of copper, either native or in ores. In his first small experiments it is unlikely that the primitive iron-maker needed a flux; as his operations grew bolder, this would cease to be the case. So various in composition are the minerals containing iron, so diverse the means required for the release of this metal, that the iron-master must soon have become a man with a wide outlook on the resources of nature. Only by repeated experiments, persisted in despite failure after failure, could he have learned what to add to his ore, so that its undesired elements might be drunk up and flow freely away. Before such a flux as limestone could be lighted upon, thousands of other substances must have been thrown in the fire, only to declare themselves inert or harmful. There must surely have been a long series of trials, conducted with high sagacity, before the efficacy of fuel itself in ridding metals of worthless mixtures could have been ascertained. Indeed, when we consider the skill of the old-time metallurgist, it is hard to believe that he was destitute of some pretty clear perception of law beneath apparent lawlessness. Be that as it may, the age of science owes much to the patience which would shoot so many arrows at a venture, content if in a lifetime one of them struck its mark.

Steel.

During all the years when copper and iron were gradually surrendering themselves to man, other metals were coming to his knowledge. We may believe, from its occurrence in native purity, that gold may have been worked even earlier than copper; its beauty, its freedom from rust, its superb malleability, would commend it to every intelligent tribe lucky enough to find it. Lead must have been known early in the day of metal-working, from the comparatively low temperature which reduces it from its ores. Then, at periods wholly beyond guessing, silver and zinc were found and used. But as time goes on, iron confirms rather than relaxes its long supremacy. Transformed into steel by adding a few tenths of one per cent. of carbon, it makes possible the cheap railroad and steamship; it builds the machines and enginery that do more and more of the drudgery of civilised nations; it is fast revolutionising the architecture of great cities, following its re-creation of the tunnel and the bridge.

It is because steel combines strength and lightness in the highest degree that we find an office building reared to thirty stories, that an ocean steamer exceeds a length of 700 feet. Engines, locomotives, and machinery are built to-day in dimensions and whirled at velocities that would have made the mechanics of the last generation stand aghast, and this while every working part is more durable than ever. So greatly is the strength of steel augmented by modern processes of manufacture that wire is now produced which sustains a load of 170 tons per square inch. No single cause has contributed more to the cheapening of freights than the building railroads of steel instead of iron. In one case steel rails have remained in use seventeen years, and borne more than 50,000,000 tons of traffic, with a loss of but 5 pounds of metal to the yard, and this while safety and speed have been much increased. To-day locomotives are constructed of steel so that they can go farther and quicker than ever before with the minimum of repairs. Freight-cars also are built of steel, so that they carry heavier loads proportionately to their weight than do wooden cars. The result is that a train now bears thrice as much freight as a similar train did twenty years ago, and charges have fallen to a point so low that the policy of maintaining canals is questioned by some of the most judicious minds in the business world.

Steel, itself a compound or an alloy, is commingled with nickel and other metals with astonishing gains in its best properties of toughness and strength. Hence the unending competition between shot and armour-plate, the one no sooner advancing to a new power of penetration than the other rises to a new resistance. Shot is now made capable of piercing 37 inches of wrought-iron, the point of the shot remaining intact, although the striking velocity is nearly 2800 feet a second. Certain nickel-steels studied by Guillaume seem to contravene all the rules one is accustomed to associate with metals or alloys: some of them do not expand with heat; others contract with heat and expand with cold. The magnetic susceptibility of both iron and steel disappears on the addition of either manganese or palladium—a fact of high importance to men as far apart as the ship-builder and the watchmaker. When the dream of the aëronaut is fulfilled and he reigns in the sky at last, it will be largely through steel, or one of its compounds, providing him with a structure which unites the utmost tensile strength with the least possible weight.

On its commercial side the expansion of the iron industry is one of the wonders of our era. A furnace at Pittsburg swallows 250 tons of ironstone at a single charge. From Lake Superior ports were shipped, in 1899, cargoes of iron ore amounting in the aggregate to 17,901,358 tons. The United States now leads the world in its production of iron and steel. In Alabama, rich veins of iron ore and of coal for its reduction lie so close together that three pounds of pig-iron were, in 1897, sold for one cent.

"Startling as the statement may seem," says Sir William Roberts-Austen, "the destinies of England throughout the nineteenth century, and especially during the latter half of it, have been mainly influenced by the use of steel. Her steel rails seldom contain more than one-half per cent. of carbon. Her ship-plates, on which her strength as a maritime power depends, contain less than half that amount. . . .

Passing now to questions bearing upon molecular activity, we are still confronted with the marvel that a few tenths per cent. of carbon is the main factor in determining the properties of steel. We are therefore still repeating the question, How does the carbon act? which was raised by Bergman at the end of the eighteenth century. That mystery is lessened now, as it is known that the mode of existence of carbon in iron follows the law of ordinary saline solution." [1]

One of the great inventions of the primeval mechanic was the wheel, which originated probably in the section of a round tree, such as the birch, used as a roller. When a wooden wheel was strengthened and smoothed by a metal tire, its friction was as much diminished as when the dragging of a load on the ground was eased by placing a roller beneath it. An advance almost as important is enjoyed to-day as hardened steel is worked up into roller- and ball-bearings. These appliances, supplanting plain axle-bearings, reduce friction to the vanishing-point in bicycles, elevators, propeller-shafts, machines and engines of all sorts.

Lessons from the Iron-master.

The art of modern metallurgy centres in the production of iron and steel; other metals are produced all the better and cheaper for the lessons the iron-master has taught his brethren. Especially important to the whole guild of metallurgists is the steady reduction in the amount of fuel needed to yield a ton of pig-iron; to-day not more than 40 per cent. as much coke is required as when small and unimproved furnaces were employed. A remarkable economy has been effected here by the hot blast, devised by Neilson. He observed that the first work that fuel had to do was to heat the air for its own combustion; thought he, "If the air enters the fire already heated,

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[1] Presidential address, Iron and Steel Institute, May, 1899.

the resulting temperature will be much higher than it is now, and much more effective—for it is the range of heat above the melting-point of the metal that really does the business." Experiment proved him right, and paved the way for Sir William Siemens's regenerative furnace.

This is so contrived that the hot gases resulting from combustion are led through roundabout chambers of brick which absorb their heat; at intervals these chambers are closed to the gases and opened to the air on its way to the furnace—which air is thus raised to a high temperature with no outlay for fuel. The apparatus is double, its halves alternating in their absorption and surrender of heat. Mr. Charles Kirchhoff, in analysing the cost of producing iron in an establishment at Pittsburg, found that the consumption of coke had been reduced 14 per cent. in the decade ending with 1897. In smelting and refining lead on an extensive scale in a Western city during the same period, the consumption of fuel declined 29 per cent. From year to year the furnaces have been improved so as to smelt with profit charges successively poorer and poorer in metal. Previous to 1890, 10 per cent. of lead was considered the minimum for satisfactory results, but, since then, ores containing as little as 6 per cent. of metal have been found rich enough to repay the smelter and refiner.[1]

The recent enormous expansion of electrical industries has given an unexampled impetus to the metallurgy of copper. Mr. James Douglas, president of the Copper Queen Consolidated Mining Company, of New York and Arizona, states (June 19, 1899): "The influence of iron metallurgy on the treatment of copper has been very marked. The hot blast has not been generally applied, owing to the mixed character of the usual charge, and to the corrosive action of the gases, which require working with an open top. But where high furnaces smelt a uniform

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[1] *Transactions American Institute Mining Engineers*, 1899.

ore, and the gases are not very sulphuretted, as at Mansfeld in Germany, hot-blast stoves like those attached to iron furnaces are used. The Bessemer converter is almost everywhere employed to concentrate matte to metallic copper. The form of apparatus is that applied in steel metallurgy, but the converter is lined with slag-making ingredients and is more rapidly corroded than the gannister of the steel converter."

The Debt to Metals.

Let us for a moment try to place ourselves at the dawn of metallurgy, an industry once so limited, now so stupendous. Let us think, if we can, what it meant to have acquired metal as a material instead of wood or stone. Our first contrast may be of oak with iron. Oak may be readily cut, sawn, and planed, while its lightness adapts it for buildings, furniture, or for the handles of tools and weapons. But, like other wood, it warps with moisture, in the tropics it is the prey of ants and other voracious insects, a fire of low temperature will consume it, and it will soon crumble to decay in exposed situations. It has strength, but not enough to serve as a knife or a bolt. Its elasticity is of limited range, so that a bow of oak may easily be snapped if overstrained by an archer. Mark now the qualities of iron: it is vastly stronger, tougher, more elastic, than oak. Fire of low temperature plays round it and works no ill. Not only is iron better where oak is good, but it has properties not enjoyed by wood of any kind: it may be melted and poured into moulds, beaten and rolled into sheets, or drawn into delicate wire. Paint easily prevents it from rusting. Alloy iron with a little carbon and straightway it is improved in its best qualities, as copper is when joined to tin. In its unapproached capacity for magnetism iron is the core of modern electric art—as we shall duly note.

Contrast, next, sandstone with iron as a material for the craftsman. Sandstone is readily cut and carved with the chisel, but it is comparatively weak and brittle. It is superior to nearly every other stone in its resistance to fire, but it has little elasticity, so that, except to support weight, where bulk is admissible or desirable, as in building, it has no great worth. Or, if instead of sandstone we take flint, a mineral which has done so much good work in the world, we find that, although its keen edge may be quickly formed, this stone has little cohesion, is brittle, and has therefore but slight durability. In no region of art do we find the wizardry of fire more striking than here: it renders obsolete many materials which once were indispensable; it creates implements of a size and strength impossible before the use of iron and steel. Metals in comparison with any other raw material of the arts have the supreme advantage of combining rigidity and elasticity, while they are at the same time plastic enough to be shaped with the punch and hammer. Toil multiplied its rewards a hundredfold when it rose to the use of metals, it easily surmounted difficulties not to be faced before metals were shaped and moulded. Their forms of use and beauty range all the way from the soup-kettle to a filigree brooch such as the silversmiths of Genoa are busy making to-day.

While art took on new refinements as its materials were refined, the kindling of fire came to its utmost elegance at the hands of the metal-worker. At the annual festival of Raymi, the Aztec priests were wont to collect the rays of the sun by a concave mirror of metal, so as to inflame a heap of dried cotton. From yet another quarter did fire create a novel means of its own reproduction—when the burning-glass bade sunshine ignite fuel for the hearth.

Let us cast a glance at eras much remoter than the times when skill had risen to the making of mirrors and lenses. Day by day, as the primitive metal-worker was adding to his stock and store through the capabilities of his servant, fire, the man himself grew richer and richer. While the things he could find or make by the aid of flame were in so many directions multiplied, equally increased were his own perceptions and thinking powers. His eye, as it ranged new ground, became alert for the lustre or the stains that betokened useful ores. His touch learned how to choose the best stones and clays for furnace and furnace-bed, the loam for moulds; it took on accuracy as it brought to truth the edge of bronze knives and sickles or chisels of tempered steel, it became refined and deft as it hammered, bent, twisted, and drew copper, gold, and iron. If a fuel was reluctant in burning, if a metal for the tenth or the twentieth time eluded his effort to free it from its ore, so much the more was his ingenuity spurred and strengthened for eventual success.

His brain, endowed with knowledge of hundreds of new substances, many of them his own creations, enriched by all the tasks his hands had learned, grew strangely resourceful, so that when a new want arose he was apt with a response to it. His world had widened throughout the whole round of its horizon; his sway over that world already bore the promise of kingship since fulfilled. Man dependent on such fire as nature might perchance bestow, and man kindling fire at will, are as creeping babe and sturdy youth. In that youth of the race were sown the seeds of skill which have since flowered in the mechanic and the mechanician, in the artisan and the artist, in the observer and the explorer, who by subtlest indirection bring within the narrow scope of sight and hearing a universe otherwise unseen and silent. When dexterity rose to the point of making fire it enlarged the sphere for its further exercise by nothing short of a celestial diameter.

CHAPTER V

MOTIVE POWER FROM FIRE

WE have seen how metals in their earliest uses were formed into tools of new strength and wearing quality, inciting their possessors to tasks impossible before.

Steam-engines.

Without metals, at once strong, durable, and resistant to flame as wood and stone are not, there could have been no advance from tools to machines, nor from machines to the engines which automatically drive them—all with vast multiplication of the fruits of human toil. But long before this employment of metals for the alleviation of human drudgery there had been a noteworthy escape from the severest burdens of labour.

Any survey, however rapid, of the advances of man since the ages when he dwelt in trees or caves, must pause to consider his weighty debt to the brutes he tamed or yoked to his service. The domestication of animals probably began with the capture of young wolves and sheep, oxen and horses, at first rather for amusement than use. Rich were the rewards of the men intelligent and forbearing enough to rear these creatures—for now they enjoyed new sources of food-supply, new aids in the chase, fresh materials for clothing, and, in the case of draught-animals, much exhausting labour was transferred to the muscles of horses and oxen. For ages all the way down to three centuries ago, man never seems to have suspected that the fuels, which did so much work for him in the forge and furnace, were able to pass to the field and there tire out the most powerful beasts ever harnessed: the identity of heat and mechanical power lay hidden from his eyes.

Although the æolipile of Hero was rotated by steam two thousand years ago by the same force that twirls the familiar fountains of to-day, there is no proof that Hero's device was applied to serious work, or followed by contrivances of higher efficiency (Fig. 7). A water-pump with its cylindrical barrel and moving piston is an old invention, and probably suggested the first form of the steam-engine. That rude apparatus was a cylinder partly filled with water and placed directly on a fire. As steam was generated the piston rose and did work; when it had arrived at the end of its journey the cylinder was cooled by dashing water upon it, and the heating and lifting process was slowly repeated. Newcomen effected a decided improvement by throwing a jet of cold water *into* the cylinder; Watt did still better when he took the steam, after it had lifted the piston, to a separate condenser permanently kept cool by a stream of water. He thus economised heat and increased the efficiency of the engine in a remarkable degree. Provided with this improved engine, the manufacturer and the miner passed at a bound from a petty to a huge scale of operations; the modern revolution of industry, with its factory system and its subdivision of labour, dates from the great saving of fuel effected in the engine of Watt.

He was fully aware that a further saving lay in the use of high pressures, but he had not boilers strong enough, cylinders true enough, nor pistons sufficiently tight for steam much beyond atmospheric pressure. As boiler-makers and engine-builders have grown more and more expert, have brought new lathes and tools of precision to their aid, steam pressures have constantly risen beyond the low range possible to Watt. Of late years the movement in this direction has been rapid. Whereas in 1880 marine engines rarely ran with pressures exceeding 75 pounds to the square inch, to-day a pressure of 150 to 200 pounds is common. Steam at 200 pounds needs but little more heat for its production than steam at 75 pounds, yet nearly double the duty may be had from it. Professor Thurston formulates the rule that the working value of steam increases as the square root of increase in pressure, so that the use of steam at 400 pounds means getting twice as much motive power as at 100 pounds. Strange to say, the higher pressure costs only one thirty-fourth more heat than the lower.

In improving the design of steam-engines, not less than in bettering their furnaces and boilers, the principal part has been played aboard ship. The mariner of old was probably the first man to turn to account the force of the winds. When the mariner of to-day furls his sails for good and all it is because he succeeds in getting more work out of coal than anybody else. When a factory engine can be so improved as to save 100 tons of coal a year, its owner increases his profits by the cost of so much fuel. With a like amelioration of a marine engine its owner saves not only in his coal bill, but he has gained more room for cargo. This is the premium which has developed at sea the utmost economies of design and operation, so as to make the marine type of engine a model to be copied on land. Within the past decade the Atlantic has been virtually bridged by a fleet of freight-vessels running at a cost so low as to bring the wheat-fields of Minnesota and Dakota to the neighbourhood of Liverpool and London. No wonder that the British farmer in his distress turns to fruit-growing and dairying!

Beginning chiefly with engines of marine type, there has been within the past fifty years a close and critical study of every source of loss, with exhaustive tests of improved modes of construction and working. As steam expands in a cylinder it chills itself, and imparts a chill to the metal of which the cylinder is built, so that the next charge of steam, as it enters, is cooled so much as to lose in extreme cases fully 40 per cent. of its working value. An important remedy for this evil is to maintain the temperature of the cylinder by a jacket of hot steam. Two other effective plans consist in superheating and in compounding. A superheater is a series of tubes exposed to the furnace gases, and so placed that the steam passes through it on its way from the boiler to the engine. When steam not in contact with water is thus raised in temperature it is no longer liable to condensation in a working cylinder. In compound engines economy is introduced from a new quarter. Two, three, or even four cylinders receive the steam in turn; because the chill due to expansion takes place, not in one cylinder, but in two or more, this chill is spread over two or more surfaces instead of over one surface, and, thus subdivided, it can be effectively offset by thorough jacketing. Compounding has also advantages from a mechanical point of view which commend it to the builders of large engines assigned, as in pumping, to constant duty (Fig. 9).

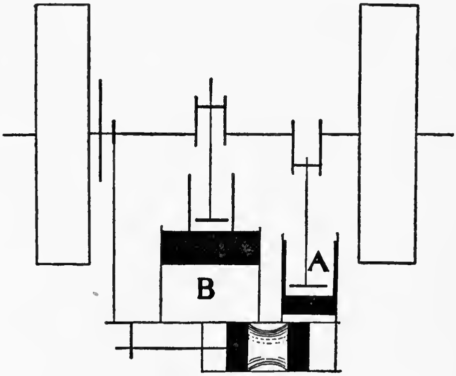

FIG. 9.
Westinghouse single-acting compound engine. *A*, high-pressure cylinder; *B*, low-pressure cylinder.

Let two remarkable feats in American and German steam-engineering be adduced: Professor Thurston, addressing the American Society of Mechanical Engineers, New York, December 6, 1899, stated that a Hall & Treat quadruple-expansion engine using steam at 400 pounds pressure, had developed a horse-power on 9.67 pounds of steam per hour. This displays a conversion into work of 25.08 per cent. of the heat value of the steam supplied. In a Schmidt compound engine at Cassel, Germany, of 750 indicated horse-power, the steam is superheated 150° C. Its "economiser" uses the same distilled water over and over again, the exhaust steam being used to heat the stream just before it reënters the boiler. This engine boasts the lowest consumption of steam on record—8¾ pounds per indicated horse-power.[1] Its efficiency is no less than 27.4 per cent. of the heat value of the steam employed. Operated with coal of high grade, and under the best conditions, a large boiler of the Babcock & Wilcox type will generate 9.78 pounds of steam of 200 pounds pressure from one pound of fuel, imparting to its water and steam three quarters of the total heat of the furnace. It is therefore clear that the engineer's long-cherished desire to obtain a horse-power for an hour from a pound of coal is gratified at last, and it seems improbable that the piston steam-engine will be much improved during the twentieth century. Increase of pressure is accompanied by such heightening of temperature that lubricating oils are volatilised, not to speak of the redoubled hazards of leakage and explosion. Having well-nigh exhausted the possibilities of invention in one path, the engineer turns to another.

The latest form of steam-engine recalls the first. The steam-turbines of De Laval and of Parsons turn on the same principle as the æolipile of Hero. That simple contrivance was a metallic globe, mounted on axes, and furnished through one of its trunnions with steam from a

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[1] *Engineering*, London, December 16 and 23, 1898.

The Steam-turbine.

boiler near by (Fig. 7). As steam rushed out from two nozzles diametrically opposite to each other, and at tangents to the globe, there resulted from the relieved pressure a swift rotation which might have done useful work. Indeed, if Hero had been able to use high-pressure steam, and had had metal strong enough to withstand the tremendous bursting tendency of great speeds, he would have had a steam-engine as efficient as many which still linger in the smaller and older factories of America. Hero's device had inherent excellence in its continuous rotation—decidedly preferable to a piston motion that may reverse its direction several times in a second. In order to return to this primitive merit it was necessary to gain skill and insight by advancing through a succession of intricate devices; a labyrinth brought the investigator at last to a height from which he could clearly discern an escape to economy. Before the steam-turbine could be invented, metallurgists and mechanics had to become skilful enough to provide machinery which may with safety rotate 10,000 times in a minute; Watt had to invent the separate condenser; means had to be devised for the thorough expansion of high-pressure steam; and the crude device of Hero had to be supplanted by wheels suggested by the water-turbine.

The feature which gives the Parsons steam-turbine its distinction is the ingenious method by which its steam is used expansively. In a piston-engine the cylinder is filled to one-twelfth or one-fifteenth of its capacity with high-pressure steam, when communication with the boiler is cut off; during the remainder of its stroke the piston is urged solely by the steam's elasticity. In the Parsons turbine, by arranging what is practically a series of wheels on the same shaft, the steam passes from one wheel to the next, and at each wheel parts with only a fraction of its pressure and velocity (Fig. 10). The illustration shows the arrangement of moving-blades and guide-vanes, the top outer cover of the case having been removed. The revolving barrel has keyed into its curve the moving-blades. The end of one row of the guide-blades can be seen in the sketch, though not very plainly. Between each two rings of moving-blades there is a ring of guide-blades, these latter being keyed into the containing-cylinder. In working, steam is admitted into the narrow space between the barrel and the case, and is directed by the first ring of fixed guide-blades in a direction spiral to the axis of the revolving barrel. The steam next comes in contact with a ring of revolving blades on the barrel. These are set at an angle so that the steam acts on them as wind on the sails of a windmill, causing the barrel to revolve. A further set of fixed guide-vanes rotates the flow of steam, and then another set of revolving vanes is impinged upon, and so on from admission to exhaust. In this way moderate pressures are obtained, and the turbine may be directly coupled to a dynamo, a fan, or a pump.

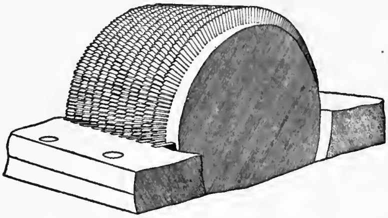

FIG. 10.

Moving-blades and guide-vanes of the Parsons steam-turbine.

The Locomotive and Steamship.

The locomotive engine was born in the coal-mine. It was because coal-wagons had long been drawn upon pairs of iron rails that at last similar rails were laid above ground, so that horses might go faster and with larger loads than upon macadam, however good. When the steam-engine proved itself so much better and cheaper than horses in turning the shafts of spindles and looms, it was asked, Why not put this machinery on wheels moved by itself, and see if it will not be cheaper and quicker than traction by horses? The experiment was tried by one inventor after another, and with fair success, but for a signal triumph, which for good and all should dismiss the horse from long-distance travel, there was needed a genius cast in the large mould of George Stephenson.

He built for the famous competition at Rainhill, October 8, 1829, a locomotive which far excelled its rivals. The Rocket won its victory by its inventor's adoption of two capital devices: first, small copper tubing for the boiler, which had the effect of greatly increasing the effectiveness of the fuel; second, a blast of exhaust-steam for his chimney, which intensified the furnace draught. The Rocket with its water—carried in a cask—weighed but 4¼ tons; it drew in its wagons 13 tons of freight; and although its average pace was but 15 miles an hour, it made one spurt at the rate of 29. Here at last was a practical locomotive, lacking nothing except to perfect the details of its design and construction. At a bound the civilised races of mankind passed from dependence on the postilion to reliance on the engineer. For all purposes of communication, whether of things, persons, or ideas, it was as if the planet had that day shrunk to one-fourth its former dimensions. A passenger locomotive built at the Baldwin Works, Philadelphia, has travelled a mile in 38 seconds; a giant engine from the same factory weighs 112½ tons, and draws on a level stretch of track no less than 5000 tons of freight (Fig. 11). In its latest and best models the engine due to Stephenson embodies the principle of multiple expansion, with the result that it holds the field somewhat stubbornly against the electric locomotive that fain would displace it.

Scarcely less important than the locomotive in making the world one parish is the steamboat, and its ally, the steamship. It was the second year of the nineteenth century when the *Charlotte Dundas* of William Symington sped its way through the Forth and Clyde Canal. Its whole bulk is to-day far exceeded by that of the machinery which drives an ocean greyhound from Southampton to New York. The Parsons steam-turbine on board ship has exceeded its performances on land. The *Turbinia*, a torpedo-boat of 44½ tons displacement, 100 feet in length, and 9 feet in beam, driven by this turbine, has consumed but 14½ pounds of steam an hour per indicated horse-power. The *Viper*, a torpedo-boat destroyer of 325 tons, and provided with a turbine capable of developing as much as 12,000 horse-power, ran at the rate of 37 knots in a rough sea during her trial trip in November, 1899. Mr. Parsons states that a cruiser furnished with a similar motor of the utmost capacity could steam economically at 16 knots an hour, and on emergency treble this speed for three hours, or maintain the gait of 45 knots for eight hours. The tactical value of such a vessel to a squadron in time of war is obvious.

It is probable that the next advance in the speed of ocean travel will be due to building steamers exclusively for passengers, relegating the carriage of freight to vessels much less rapid and costly. The builders of the *Turbinia* have prepared designs for an ocean liner of 600 feet in length, of 18,000 tons displacement, and of 38,000 indicated horse-power. Her ocean speed is estimated at 26 knots an hour; her total engine-room weight would be reduced to about one-half that of ordinary engines, while there would be, it is claimed, a small reduction in steam consumption to the credit of the new motors.

In both its stationary and marine designs, the steam-turbine marks a distinct advance upon the piston-engine. It weighs less, it occupies less room, it costs less at first and for attendance and repairs, it asks for no expensive foundations as it does not require to be bolted down.

FIG. 11.

Baldwin locomotive, built for the Lehigh Valley R. R. Co.
Weight, 225,000 pounds.

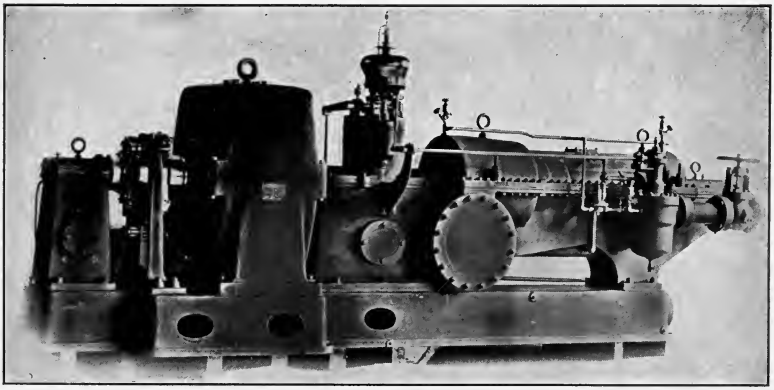

FIG. 12.

Westinghouse-Parsons turbo-alternator.
500 horse-power capacity at 125 pounds steam-pressure condensing; 3600 revolutions per minute.

Because no lubricant enters its steam-space, the exhaust is free from oil, much to the benefit of both the boiler and the condenser. A ship driven by a turbine is much freer from vibration than if a piston-engine were employed. Let the steam-turbine on land or water give as much power from a pound of coal as a compound piston-engine, and it will soon have the field to itself (Fig. 12).

National Aspects of Modern Locomotion.

Proficiency in the use of fire in metal-working has advanced side by side with proficiency in the application of fire as the motive power for transportation. The national aspects of the two, as to-day they mutually aid and promote each other, was touched upon in an address by Mr. James Douglas, delivered as president to the American Institute of Mining Engineers, San Francisco, September 25, 1899:

> This obliteration of distances by steam-power has altered completely the social conditions of the country. Before the railroad and steamboat wrought the industrial unification of the continent, not only were food and clothes the product of local and domestic manufacture, but such a necessary article as iron was cast in small furnaces or reduced in small bloomeries, wherever iron ore and charcoal were found in even limited quantities near a water-power. To transport either fuel or ore any distance over bad country roads to large establishments was less economical than running the village furnace or forge. In 1840, therefore, the furnaces, bloomeries, and forges were scattered over the land to the very outskirts of civilisation in Michigan and Wisconsin. Soon after that date commenced the concentration of raw material and the shifting of the centres of the iron industry to a few favoured localities. The process has continued ever since, to the serious detriment and even destruction of some of the older mining and metallurgical districts, while prosperous communities have been created in what a generation or two ago was an inaccessible wilderness. Ore and fuel need no longer be in natural juxtaposition, for ore from the Mesabi Range can be transported 50 miles by railroad, transferred to a vessel for a trip of 800 miles by water, re-transferred to cars for a further journey of 80 miles, and delivered at so low a figure at Pittsburg that steel rails made from it by the aid of mechanical appliances have been sold at $17 per

ton. It is less than a generation ago that Bessemer rails made by the same process, but out of costlier ores and by cruder appliances, cost $120. In very truth, so obedient have the forces of nature become to the will of man that weights and distances that in the days of manual labour and horse-cartage were controlling considerations, are being almost eliminated from the calculations of modern engineers.

Economy in Details.

During 1898 Great Britain consumed 76,000,000 tons of coal in the production of power for industrial purposes. During the same period, the United States, in all likelihood, burned one-third more. No wonder that of late years the time-honoured agencies for the production of steam-power have been sternly catechised as to their performance of duty, and have been quickly cast aside as more efficient rivals have appeared. Improvements in detail began, indeed, long ago. At first, just as in a common cook-stove, the steam-boiler stood quite outside the fire. A long stride ahead was taken when the fire was put *inside* the boiler, first in a single flue in the Cornish type, and then in two flues in the Lancashire type (Fig. 13). If two flues were better than one because they extended the surface at which flame could do work, would it not be still better to multiply the two into scores? Flues were multiplied accordingly and reduced to the small dimensions familiar to the present hour in the boilers of locomotives. Because the tubes were narrow they brought a new advantage: they could safely be made thinner than large flues or big

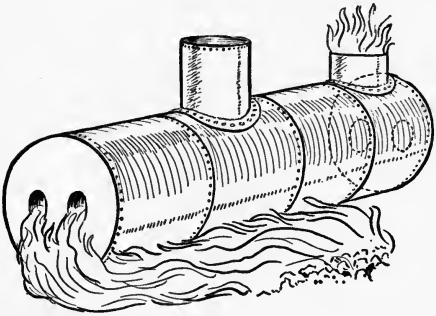

FIG. 13.
Lancashire boiler.

boilers, and so heat could pass through them more easily. With this benefit, however, there came a serious drawback. Soot and ashes are apt to gather inside a fire-tube and seriously interfere with its heating power. The remedy for this is ingenious enough: the tubes, inclined in position, are filled with water instead of fire, and are put in the hottest part of the furnace. Of course, soot and ashes collect upon them there, but never to so formidable a degree as within the body of fire-tubes, and always so as to be readily removable (Fig. 14). The water-tubes are connected with a boiler, reduced in size, which serves as a reservoir for both water and steam (Fig. 15).

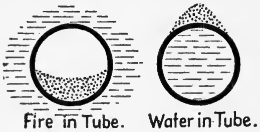

FIG. 14.

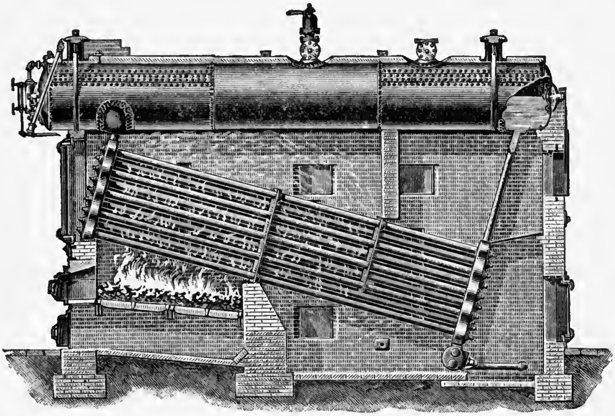

FIG. 15.
Babcock & Wilcox water-tube boiler.

As in many diverse industries, we here can note how advance in one application of fire promotes economy in another. In the construction of the modern boiler there is great advantage in the adoption of steel, which is so strong as to be available in thinner sheets and tubes than the wrought-iron originally employed. Beyond this gain there is further benefit at hand. Mr. A. F. Yarrow, the eminent builder, stated before the British Institution of Naval Architects, July 21, 1899, as the results of experiments, that nickel-steel containing 20 to 25 per cent. of nickel is much longer lived than the mild steel in ordinary use. The alloy resists corrosion almost thrice as well as mild steel, and deteriorates only one-half as much from the action of gases and steam. Stronger materials mean bigger boilers and engines. The New York Gas, Electric Light, Heat and Power Company is installing in its new station at the foot of East Thirty-ninth Street a generating plant designed by the company's constructing engineer, Mr. John Van Vleck. Each of the sixteen engines to be employed will be of 5200 horse-power, working up to 8000. With such dimensions arrive new economies. If the designer sticks to the same forms he finds that the contents of a boiler and the power of an engine increase as the cube of their lengths, while the surfaces injuriously cooled by radiation and conduction increase only as the square of these lengths. To take a simple case: an enlargement to doubled size signifies eightfold increase of capacity or power, and but fourfold augmentation of surface.[1]

Economy, instead of waste, appears in other directions. The air on its way to the furnace is now warmed through a considerable range of temperature by being exposed in pipes to the heated gases as they enter the chimney from the fire. The heat thus intercepted was formerly thrown away. Of course, this interception adds a little to the resistance encountered by the chimney gases as they escape to the outer air. Here, too, improvement is the order of the day. The modern builder, instead of designing a tall chimney of the old pattern, which by its long column of

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[1] The law of volumes and surfaces here concerned is developed and illustrated in *A Class in Geometry*, by George Iles. New York and Chicago, E. L. Kellogg & Co.

heated air created a draught, to-day erects a low chimney and employs a fan to produce a draught, which is much preferable. In the first place, it is most wasteful to warm air simply for the current which heat sets up in it; a similar current can be furnished with a mere fraction of the same heat applied to a steam-engine driving a blower. Mechanical draught has many advantages: it not only dispenses with high and costly chimneys, but it is easily controlled in bad weather, or when there is an unusual demand for power; it enables both boiler and engine to be reduced in dimensions; inferior fuels of low cost are readily consumed; it prevents smoke; and on shipboard, as elsewhere, it lends itself to thorough ventilation.

For a good many years mechanical stokers have been devised in various forms; they are steadily coming into favour in improved and economical types, completing the modernisation of fuel-burning, and abolishing a most oppressive form of drudgery. As the automatic hopper, filled with fine coal, glides to and fro above a furnace provided with moving grate-bars, we behold the latest term of that marvellous advance which began when the savage first laboriously kindled a blaze to warm his hands or to cook his breakfast.

The Gas-engine.

For twenty years, or thereabout, the steam-engine has been confronted with a rival in the form of the gas-engine, for centuries prophesied in the common gun. In the gun a charge of powder takes fire and is for the most part suddenly transformed into gases of enormous tension. The gunpowder is at once the fuel and the expanding medium whose motion wings the bullet. In effect, therefore, the gun-barrel is both a furnace and a cylinder; the bullet is virtually a piston driven with an efficiency far exceeding that of any other form of heat-engine. The gas-engine, at moderate and safe pressures, copies all this. Within its cylinder the gas is both fuel and expanding agent. Because it has no special furnace or boiler its construction and working are much simpler than those of the ordinary steam-engine. In its recent and much improved forms the gas-engine has been built in sizes capable of exerting 750 horse-power. For the same quantity of applied heat it yields more work than the ordinary steam-engine, but as gas usually costs more than other fuel, the balance of advantage remains in most cases with the older apparatus. Machines for generating fuel-gas from coal have been designed by Dowson, Benier, Taylor, and others; when operations are on a large scale their use is decidedly gainful. At Jersey City the Erie Railroad Company installed at its shops, during the summer of 1899, a Taylor producer gas plant designed and built by R. D. Wood & Co. of Philadelphia. This plant records the consumption of but 1.1 pounds of rice coal, of low price, per horse-power hour, while the average duty of the engines is 22 per cent. of the theoretical value of the fuel consumed.[1]

The constant improvement of the gas-engine and the gas-producer does not mean the supersedure of the steam-engine, but only that the engineer has a new choice in the production of motive power; he may have preferences, but no exclusions. Where he has work to do on a small scale, or of an intermittent character, he may find it better to buy illuminating-gas for use in his cylinders, than to keep up steam in a boiler called upon during only a fraction of the day. Often, too, the availability of exhaust-steam for heating a building, as is often required in the Northern States and Canada, turns the scale in favour of a steam plant of familiar type. Each case has to be studied in the light of its peculiar circumstances.

In one important department the gas-engine is creating a field for itself—by working with gases formerly thrown

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[1] *Engineering and Mining Journal*, November 4, 1899.

wastefully into the air. In iron-making there is a huge output of blast-furnace gases now beginning to be utilised for the production of power at nominal cost. Experiments at the Cockerill Works, Seraing, Belgium, prove that the heavier particles of dust carried in the gases are quickly deposited by a simple arrangement of passages and collecting-chambers. There remains only a light, impalpable dust, which goes through the engines so rapidly as to do no harm whatever.

The Growth of Initiative.

When a savage softened or melted a lump of copper in a blaze, his act was one of direction rather than of execution; to have warmed the metal by repeated blows would have been a toilsome and unrewarded task, while to place the copper in the flame and duly to remove it, was labour of an unexacting and most fruitful kind. So, too, when heat-engines of constantly improved types came into the mines, the shops and factories of the world, and were last of all adapted to transportation, the work that a skilful man could direct became immensely greater and bolder than the task he could perform by dint of exerting his own muscles. In this passing to more and more of initiative consists an important phase of civilisation, as we shall perceive in future chapters no less clearly than here.

As heat-engines of one type and another grow in economy, each adapted to the circumstances of its case, by just so much do they maintain their ground against water-powers, except when these are easily available and constant. Fuels, for a reason which will be manifest as we proceed, seem to be destined long to retain their predominance as sources of motive power. Every improvement, therefore, in heat-engines is of prime importance to the electrician, whose labours we shall presently consider; it is commonly with the production of motive power that his tasks begin.

CHAPTER VI

THE BANISHMENT OF HEAT

WE have thus far considered the gifts of fire as directly applied to warming a habitation, to boiling a kettle or a still, to yielding light, in fusing metals, in smelting their ores, in propelling machinery. We are now briefly to glance at the skill which builds an apparatus, and dividing the heat within it into two parts, obliges one of these parts to expel the other. In this remarkable branch of art, the most striking, and perhaps the final, developments have taken place within recent months, but the first steps were familiar enough centuries ago.

Heat Produces Cold.

It is altogether likely that in the day of Columbus ice formed on peaks such as those of the Sierra Nevada, near Granada in Spain, would be carried to the sweltering valley beneath, for the refreshment of king and court. Here would come into play the virtues of non-conductors such as gypsum or ashes—the very material that would preserve the heat of an ember prolonging the life of an ice-block. Whether heat is to be kept in or kept out, a non-conducting cloak is of equal service. Few capitals have so happy a site as Granada, and, therefore, other means of lowering high temperatures than by ice have been in request from remote antiquity. Of these means the commonest has been the mimic breeze blown by slaves toiling at huge fans or overhead curtains, as in modern India. Here, for all who cared to think about it, was a hint as to the equivalence of hard work with an effect on temperature. Here, also, was a plain lesson that to promote evaporation from the skin, or other surface, is to produce a cooling effect.

Usually there is a flow of heat from surrounding bodies to a liquid as it evaporates at nearly the temperature of common air, and when the evaporation is slow this cooling is not readily detected. But when the evaporation is rapid, and the body from which it takes place is isolated, it is easy to remark a decided fall in temperature. If a porous jar filled with water is hung by a thread in a quick draught of air, the heat demanded by the evaporating process is withdrawn solely from the jar, which accordingly soon exhibits a chill. Indeed, the familiar misfortune of "catching cold" in a similar draught has points of resemblance to the elaborate artificial refrigeration which to-day yields ice by the car-load.

The Evaporation of Liquids.

All liquids at all temperatures tend to evaporate, and the search of the investigator has been directed to ascertaining which liquids evaporate most rapidly. Among these is alcohol. If a few drops are allowed to fall on the hand they turn to vapour so quickly as to excite a sensation of cold, giving us our first lesson in the refrigerating value of such a liquid when free to change to vapour. If alcohol cost as little as water, and if its fumes were not inflammable, it would be a capital refrigerating medium. But anhydrous ammonia is, from every point of view, the most preferable of all liquids as a means of procuring artificial cold. It tends to evaporate so rapidly at common atmospheric pressure that it quickly chills itself in the process. Of course this evaporation is swifter still when an exhausting-pump reduces the atmospheric pressure; and quite as important is the fact that, at comparatively moderate pressures, this ammonia vapour is readily reduced to the liquid form once more. A simple refrigerating apparatus is shown in Fig. 16. It consists in a steam-engine, *C*, whose first business is to reduce the pressure from the surface of the liquid ammonia *A*. The resulting chill of rapid evaporation is communicated to *B*, a tank filled with brine—which remains liquid at temperatures below the freezing-point of water. Pans of water exposed to pipes of chilled brine are readily congealed to ice. As the second half of its recurrent task the steam-engine withdraws the ammonia vapour to a chamber of its own, where it is compressed again to liquidity and returned to its original reservoir, care being taken that the heat generated in this compression is carried off by water flowing over the apparatus.

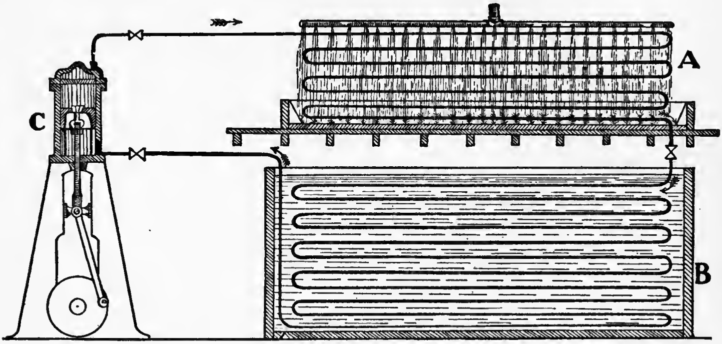

FIG. 16.
Refrigerator, Frick Co., Waynesboro, Pa.
A, ammonia; *B*, brine; *C*, engine, by turns exhauster and condenser.

Thus, since heat is transformable into motive power, and motive power can force ammonia to chill itself, a ton of coal, according to quality, can make six to ten tons of ice in competition with the frosts of winter. Because their product is pure, refrigerating-machines are finding more and more favour in cities once supplied exclusively with ice from ponds and streams. At another point does art here supersede nature. The ammonia-machine stands for the type of apparatus which depends upon the evaporation of liquids low in boiling-point, the process usually taking place in a receiver exhausted as thoroughly as possible.

The Market Value of Cold.

Cold, so singular an issue of heat, has high commercial value. Apples and grapes harvested in September and October are sent from the cold-storage warehouse to the table in perfect order as late as May. The fruit-grower and the dairyman have a new opportunity to choose the time for marketing their products. Refrigerator steamships now carry Canadian butter and New Zealand meat in vast quantities to the markets of Great Britain. Within the shorter distances traversed by the railroads of the United States, the strawberries of Oregon find their way unbruised and fresh to St. Paul and Chicago, while the kitchen-gardeners of Florida and Louisiana look for their customers in New England and New York. There is more in all this than the mere purveying of luxuries: there is an increase of individual health and strength when a national bill of fare is at once diversified and made more wholesome. Whereas heat in the hands of early man served to multiply his foods by primitive methods of roasting, of smoking, of preservation in grease,—as pemmican,—the later applications of heat by the modern engineer are of comparable service in multiplying the food resources of the civilised world. Cold storage and quick transportation supplement in remarkable fashion every device that has sprung from the aboriginal grill and kettle.

Refrigerating machinery bids fair before many years to add still other blessings to those we owe to steam. What is to prevent the cooling of summer air in dwellings, offices, and stores by apparatus sending currents of cold water through pipes such as we fill with hot water in winter?

Of course, the details of service would have to be totally reversed—the current starting from the top of a building instead of from the basement, the coils being fastened to the ceiling in place of to the floor.

New Depressions of Temperature.

The cold required in the cold-storage room is usually a degree or two above the freezing-point of water. A much lower temperature displays effects unknown till within the past decade. We have observed how ammonia, as used in ice-making, is readily brought from the gaseous to the liquid form under pressure. Other compounds there are which demand for the same transformation lower temperatures and severer pressures; and these when allowed to evaporate freely become chilled in extraordinary degrees. And here we come to one of the partition-walls that have been pierced by the modern physicist, with new proof that the realm of nature is one and continuous, however convenient it may be to imagine fences here and there so as to divide her territory into governable provinces. A century ago it seemed that aëriform bodies might with propriety be divided into two quite distinct classes — vapours, such as steam, and gases, such as oxygen. Faraday did much to correct this assumption: he showed that carbonic dioxide, chlorine, and many other gases are condensable into liquids; but nitrogen, oxygen, and hydrogen resisted his utmost skill.

A new distinction was thus introduced—between gases condensable and gases "permanent." We are now to observe the steps by which it is proved that no gas is permanent, that no line of demarcation can be drawn between such a vapour as common steam and so resistant a gas as hydrogen. This gas, together with oxygen and nitrogen, are indeed nothing else than the vapours of liquids which boil at extremely low temperatures, and which solidify at temperatures a little lower. The mind is accustomed to associate boiling, as in the case of water, with a considerable degree of heat; we have to pause a moment to comprehend that the boiling of liquid oxygen, nitrogen, and hydrogen takes place at temperatures compared with which those of the arctic circle are torrid. The feat of producing hydrogen in solid form marks the highest triumph of experimental resources, and has been arrived at only through a patient series of approaches.

In preliminary investigations it was found that ammonia at a pressure of 115 atmospheres boils at —33° C.; nitrous oxide, at a pressure of 75 atmospheres, boils at —87° C.; and ethylene, at a pressure of 51 atmospheres, boils at — 102° C. Here the man of experiment is at once a chemist and a mechanic; his chemical compounds enable him to descend from one level of refrigeration to a lower one, while, from first to last, it is of vital importance that his cylinders be of the utmost strength, and his pistons tight and true. In this difficult field M. Cailletet of Châtillon-sur-Seine, in 1877, succeeded in liquefying oxygen and carbonic monoxide. Three weeks later, by a distinct apparatus, M. Pictet of Geneva liquefied oxygen. Six years afterward MM. Wroblewski and Olsewski of Cracow, by original methods, liquefied oxygen, nitrogen, and carbonic monoxide. Clearly there is more than one point of attack in reducing to liquid form the gases long deemed "permanent." Each successive experiment but serves to verify the dictum of Faraday and Andrews to the effect that no matter how severe the pressure to which a gas is subjected, that pressure will not avail for its liquefaction unless its temperature is lowered to a "critical" degree.

The most remarkable recent work in refrigeration is that of Professor James Dewar, of the Royal Institution in London. The feat of liquefying oxygen by a succession of approaches to its critical temperature has been thus described by him, in an interview which appeared in *McClure's Magazine*, November, 1893:

> The process of liquefying oxygen, briefly speaking, is this: Into the outer chamber of that double compressor I introduce, through a pipe, liquid nitrous oxide gas, under a pressure of about 1400 pounds to the square inch. I then allow it to evaporate rapidly, and thus obtain a temperature around the inner chamber of —90° C. Into this cooled inner chamber I introduce liquid ethylene, which is a gas at ordinary temperatures, under a pressure of 1800 pounds to the square inch. When the inner chamber is full of ethylene, its rapid evaporation under exhaustion reduces the temperature to —145° C. Running through this inner chamber is a tube containing oxygen gas under a pressure of 750 pounds to the square inch. The critical point of oxygen gas—that is, the point above which no amount of pressure will reduce it to a liquid—is —115° C., but this pressure, at the temperature of —145° C., is amply sufficient to cause it to liquefy rapidly.

In May, 1898, Professor Dewar, by the use of liquid oxygen, succeeded in liquefying hydrogen, producing a liquid having but one-fourteenth the specific gravity of water; this exploit brought him within 21° of the absolute zero of centigrade. He afterward reduced the liquid to solid form, attaining a temperature estimated at four to five degrees lower. Faraday and other investigators of an earlier day surmised that hydrogen, when solidified, would prove to be a metal; now that the feat of solidification has been accomplished, hydrogen astonishes the physicist by displaying itself as non-metallic.

Air Compressed, then Expanded.

In feats much less audacious, refrigeration manifests itself every day in our mines and quarries. We have already glanced at ice-making as due to the spontaneous evaporation of a liquid, such as ammonia, of low boiling-point. Let us now look at the drills of the miner and the quarryman as driven by compressed air. At headquarters, air for their supply is compressed to a pressure of 200 pounds to the square inch, or thereabout. In the process there is a marked evolution of heat—which is carried off by a stream of water surrounding the air-pipes. As the compressed air expands in driving its pistons, it falls so much in temperature that it would be easy to freeze water by its means. This chill of expanding air as it pushes a piston is one and the same with the lowering of temperature in a steam-cylinder as its contents impel the piston of an engine. The heat which in each case disappears is precisely equal to the amount which the piston-stroke would generate, were it employed, let us say, in rubbing iron plates together (Fig. 17).

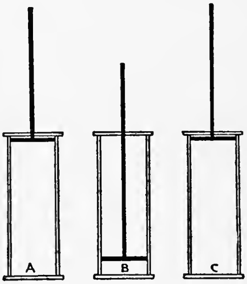

FIG. 17.

A, air at ordinary pressure; *B*, air heated by compression; *C*, air then cooled by expansion.

We are here observing the conversion of heat motion into mechanical motion; it is very much as if we beheld a target moving before a storm of fine shot. Heat consists in the motion of molecules, and as they part with much of their momentum in the act of impelling a heavy piston, their loss of motion is declared in their perceptible fall in temperature. When a compressed-air motor is at work this fall of temperature is evident to the touch; in the case of a working steam-cylinder the effect requires a thermometer for its detection, since the steam even when lowered in temperature is still very hot. The cooling effect derivable from the expansion of compressed air underlies the self-intensifying process of refrigeration now to be described.

In many of its chapters, the history of invention displays an advance from the roundabout to the direct, as we have seen in the substitution of the steam-turbine for the compound engine. Recent modes of refrigeration offer a like illustration. For some years the plan was to employ a series of chemical compounds, each with a lower boiling-point than its predecessor in the process, and all troublesome and hazardous in manipulation. A better method has been developed by keeping to simple air from first to last, as in the apparatus of Dr. Linde, of Dr. Hampson, and of Mr. Charles E. Tripler.

Liquid Air.

As the Tripler machine does its work on a bolder scale than either of the others, let its operation be briefly outlined: Air is first compressed to 65 pounds pressure to the square inch; through a second pump this pressure is exalted to 400 pounds, and with a third pump the pressure is carried to 2500 pounds. After each compression the air flows through jacketed pipes, where it is cooled by a stream of water. At the third condensation a valve, the secret of whose construction Mr. Tripler keeps to himself, permits part of the compressed air to flow into a pipe surrounding the tube through which the remainder is flowing. This act of expansion severely chills the imprisoned air, which at last discharges itself in liquid form—much as water does from an ordinary city faucet.

Absolute Zero.

It has been said that Professor Dewar, in producing liquid hydrogen, has come within 21° of the absolute zero of temperature. It may be asked, How do physicists know where to place this point in their scale? The answer is that all gases are doubled in elastic force when, without change of volume, their temperature is increased from 0° to 273° C. Assuming the same law to hold good from 0° downward,—that for every degree of refrigeration we diminish its elastic force, or the molecular motion which produces it, by $\frac{1}{273}$ of what it possesses at 0°,—then at a temperature of 273° below zero the gas would cease to have any elastic force whatever. The motion to which elastic force is due having vanished, we reach what is called the absolute zero of temperature. We have withdrawn from the gas just as much heat as we added to it when we warmed it from 0° to 273°.

Degree for degree the deprivation of heat works changes more remarkable than does addition of heat within familiar bounds. When a substance is once warmed to the gaseous state, we may heat it as much as we please, it remains gaseous still. But when a gas or vapour is so cool as to be near condensation into liquid form, the change wrought by a moderate degree of refrigeration is very marked, and a totally new series of properties rises to view; with another and still moderate cooling, the substance becomes a solid displaying a totally novel aspect from the mechanical and physical standpoints. The difference between a gas at low temperature and the same gas highly heated is a difference of degree; the distinction between a gas, a liquid, and a solid is a distinction of kind.

Discoveries.

The alterations of quality which display themselves under the new refrigeration are most significant. Iron, in falling from 100° C. to the temperature of liquid air, —191°, gains fifteen times in electrical conductivity; hence it is believed that at absolute zero, iron and other metals would be perfect conductors. Professor Elihu Thomson thinks that it may be profitable to employ intense cold as a means of increasing the efficiency of electrical transmission to long distances. Why not also in improving the economy of dynamos and motors, advantaged as these are by compact shape? Carbon is a singular exception to the general rule that cold increases conductivity; at extremely low temperatures its resistance is extreme, and steadily diminishes as its temperature rises. Subjected to the new refrigeration, lead gains enormously in tenacity, ice becomes brittle, and photographic effects slow down and all but cease; alcohol, chloroform, and other important compounds become solid, and in so doing rid themselves of admixtures.

A wide variety of substances change colour when reduced from glowing heat to common temperatures, the metals, notably. Just as decided is the change of hue when many chemical compounds are brought from ordinary temperatures to extreme cold. Red oxide of mercury turns yellow, sulphur and potassium bichromate turn white. A solution of iodine in alcohol becomes colourless; so does ferric chloride, which is a deep red under ordinary circumstances. A new chapter in the story of heat is thus being written day by day, and one of the most astonishing, because until within a few years the appliances for the forcible expulsion of heat were not perfected.

Unexpected Aid.

A thought often in the mind of Professor J. Clerk-Maxwell was the "cross-fertilisation of the sciences." He was wont to point out how a new discovery or invention bore fruit in the most unexpected quarters, and gave aid in emergencies that would seem without hope. Who at first view would suppose that the new extremes of cold would afford the closest known approach to a perfect vacuum? Yet such is the fact, with all that it means for the advancement of incandescent lighting and other branches of electric art. By dipping the end of a closed bulb filled with air into liquid hydrogen, the air is quickly condensed at the bottom in solid form (Fig. 18). The bulb is so shaped that this condensation takes place in a detachable part, *B*; sealed off by the flame of a blow-pipe, at *N*, the remainder of the bulb furnishes a vacuum which is so nearly perfect that an electrical charge cannot pass

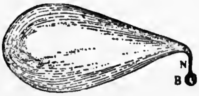

FIG. 18.
Vacuum obtained by freezing air by liquid hydrogen.

through it. This nearest of all approaches to complete exhaustion is due to the skill of Professor Dewar. A bulb thus emptied by utmost cold is an example among thousands that troop before the observer, all disclosing the threads which bind utilities, apparently, at the first thought, too remote from each other for any alliance. It is these cases which bring permutation from the clouds of mathematical theory to the solid earth of scientific evidence.

In another unlooked-for affiliation an old use of heat teaches a lesson to the new extreme of cold. For ages the chemist has employed fractional distillation as one of his most useful methods. To take a modern instance: Petroleum, as it flows from a well, is slowly raised in temperature until the lightest of its naphthas is driven off by heat. When that operation is at an end, the temperature is slowly raised a little more, then another naphtha, not quite so volatile as the first, is separated, and so on with a succession of hydrocarbons till at last a heavy oil, useful, perhaps, as a lubricant for heated machinery, remains alone in the still. Who at the first blush would suppose that such a process as this would bear a hint for Mr. Tripler, working as he does at ultra-arctic temperatures? But so it is. The gases on which he exerts his skill have their boiling-points just as oils and water have theirs, and by carefully graduating his temperatures he can effect separations every whit as important as those by the old-time fractional still. The boiling-point of nitrogen is about 7° C. below that of oxygen. When liquid air stands in a trough and is slowly raised in temperature, its nitrogen becomes gaseous first, leaving behind it a mixture which from moment to moment grows richer in oxygen—a substance of especial value in the arts when it can be secured by itself, or with small admixture. On the same principle, Professor Ramsay has performed an astonishing feat: from a vessel containing a liquid mostly argon he has obtained two new elements, neon and xenon, which, from their higher boiling-points, successively remained behind after the argon had evaporated.

Anomalies.

Alloys, so puzzling in other of their properties, do not improve in electrical conductivity under refrigeration in anything like the same measure as simple metals. At this point a contrast is suggested between the studies of the man of science and those of the man of law. Jurisprudence in its consideration of the conflict of laws has a department of more than common interest to the layman. A citizen of Kansas, let us suppose, is permitted by a United States statute to do a certain act, while a law of his own State forbids him to do it under penalty. From this may issue a prolonged contest, simply because the legislators of the nation and those of the State have not worked in harmony—because the laws of one, or both, do not express justice.

The man of science, like the man of law, has brought before him many an anomaly; but, unlike the judge or the advocate, he knows that the contradictions he studies are only such in seeming: he feels confident that nature at the core is in agreement with herself. Any day, he believes, these apparent contradictions may be resolved into cases of detected law, not simple enough to disclose itself to aught but the most rigorous analysis. In the realm of heat it seems that certain rules of radiation, conduction, boiling-points, and the like, are general, not universal. In most cases they act as if alone; in a few cases their effect is masked by causes as yet not understood. Let a few cases as perplexing as that of the alloys under refrigeration be recounted: Common solder has a lower melting-point than any of its ingredients. Sulphur fuses at 120° C., and thickens again at 220° C. When steel is heated and dipped into cold water it is hardened; the same treatment softens copper. While almost every substance expands with heat, rubber shrinks. In most cases electrical conductivity is impaired by increase of temperature, yet a carbon pencil rises to an almost threefold augmentation of conductivity when brought to incandescence in an electric lamp. We may be well assured that when these anomalies are resolved the explanations will bear in their train other difficulties for research yet more subtile. Science never does worthier work than where, as here, she points to her own unfinished walls, and bids the student as a privilege and a duty to supply their gaps as best he may.

The Profit of Subtraction.

Incalculable as the value of heat is in its uncounted direct applications, it is quite within the bounds of probability that many of these uses are soon to be paralleled or outdone by the very banishment of heat. Within limits long ago compassed, cold suspends the chemical changes which mean the decay of foods, the deterioration of oils or of many other compounds important in the arts. In its new and extreme degrees, refrigeration brings to the liquid and even to the solid form some of the prime elements of chemical industry. When oxygen, nitrogen, and hydrogen can be produced, shipped, and manipulated in as compact form as so much petroleum, and almost with the same ease and safety, a new era dawns in the laboratory and the workshop. So singular are the changes of properties which come about in extreme refrigeration, so unexpected are its disclosures, that the man of research has now in his hands a power every whit as fruitful as if he had discovered some method of heating his furnace to a new intensity.

And all this is not without precedent in other fields. Air is indispensable in almost every task of the mechanic and the chemist, but mark the value of the means whereby air may be banished from a boiler or a still—affording a new range of working to the refiner of sugar, oil, or alcohol. On a vacuum approximately perfect turns, as we shall presently see, the success of an important branch of electric lighting. In the insulation from heat of vessels containing frozen hydrogen and similar elements, the chief part is played by a vacuum between the container and an outer shell, both of glass; in the absence of air or other gases there are no currents to convey heat from the shell to the vessel separated from it by an inch or two of empty space (Fig. 19).

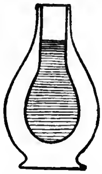

FIG. 19. Dewar flask for holding intensely cold liquids.

And to pass from the phenomena of heat to those of light, to what do we owe the whole world of colour but to the power by which surfaces select from white light certain of its component rays, reflecting the remainder to the eye? Every tint and hue of the chromatic scale is a gift of subtraction.

CHAPTER VII

THE HIGHER TEACHINGS OF FIRE

What is Radiant Heat?

WHILE fire has been multiplying its material gifts to man, it has created uncounted objects for his highest curiosity. In refining sugar and oil, in producing acids, dyes, and chemicals by the thousand, in vulcanising rubber, in making gas for illumination, flame has but performed its lower services. Its loftier incitement has lain in prompting the student to pass from act to agent, to ask, What is the nature of heat, what medium propagates the solar ray, and what are the ties between heat and light and common mechanical work? At sunrise all the rays of the sun, luminous and thermal, arrive at the earth together, just as all the sound-waves of an orchestra, multifarious as they are, travel in company from the instruments to the ear. That heat and light are twins inseparable has often meant loss when light alone has been in request, yet there has been a remarkable extension of knowledge of heat through study of light.

First came Römer's observations, in 1676, of the eclipse of the satellites of Jupiter, establishing the velocity of light as 186,500 miles a second, a velocity, of course, shared by radiant heat. Römer's computation, substantially confirmed by Bradley, at once suggested, What medium is it that transmits motion at a rate so prodigious? Is it a gas, a corpuscular rain, or an ether—a more subtile kind of matter than visible or tangible bodies, and supposed to exist throughout all space, whether occupied by ordinary matter or not? Newton lent his great name to the corpuscular view. Huygens advanced the theory of undulations in an ether—now universally accepted as the one satisfactory explanation of the facts.

The Argument for Ether.

Young, in arguing for the theory of Huygens, drew attention to a common experiment with water-waves. If from two centres of motion two series of waves circle out, wherever a crest from one centre meets a crest from the other the two rise to a doubled height; when a crest meets a trough, one cancels the other, and the water at that point is at rest (Fig. 20). He repeated this with light in a convincing manner. By simple optical means he divided a beam into two parts, one part half a wave-length behind the other. The two, after travelling by different paths, he reunited and let fall upon a screen. If either ray were stopped, the other shone forth upon the screen, but if both were allowed to pass, the screen at regular intervals became dark. Two portions of light had destroyed each other through the coincidence of a crest and a trough, as in the case of the water-waves (Fig. 21). Young from this concluded that light must be merely a motion, and not a substance; for how could a substance be thus annihilated? Nevertheless it is held that the ether

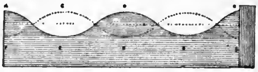

FIG. 20.
Water-wave in dotted outline neutralises wave in continuous outline, producing level surface.

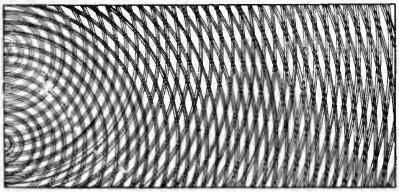

FIG. 21.
Interference of light-waves.

through which light and heat take their way is a substance, though of a tenuity so extreme as to be next to nothing. Professor de Volson Wood computed that a mass of it as large as the earth would weigh but 1.7 pounds. Lord Kelvin tells us that in a cubic mile of it surcharged with sunshine there resides but 20,000 foot-pounds of energy, no more than the equivalent of the exertion of a horse during thirty-six seconds.

Within the limits of a single viewpoint the comparison of gases enables us to approach an explanation of the ether. Hydrogen, which is about one-sixteenth as tenuous as oxygen, transmits sound nearly four times as fast. If we can imagine a gas so much more tenuous than hydrogen as to convey motion with the speed of light, we may form an idea of the ether, and attempt, at least, to include the ether with ordinary matter as making up one continuous scheme of things. The question as to whether ordinary matter has originated from ether or not remains to be considered by the inquirers of the future.

In bringing the man of science to the knowledge of ether, the study of light and heat has borne its worthiest fruit. An incalculable expansion of human thought has attended the proof that an ocean as wide as the universe bathes every particle of matter, and binds it to every other with bonds more rigid than links of steel. Ether, unseen and unfelt, except to the eye and grasp of reason, explains so many phenomena of light and heat as to be deemed not less real than air or water. And the laws of ethereal motion as manifested in the rays of flame have prepared the philosopher to study electricity aright. Every extension of electrical science only confirms the belief in that universal medium for which Huygens and Young argued when the evidence for it was not one-hundredth part as weighty as it is to-day. To formulate a theory of the ether, so that from the simplest assumptions may be deduced the facts of electricity, magnetism, and optics, is the chief aim of modern physical philosophy.

Heat Proved to be Motion.

Heat, though radiated with almost infinite velocity, is conducted with extreme slowness, and so the physicists of the eighteenth century clung to the old notion that heat is a material substance, phlogiston or caloric, which a body may absorb or expel much as a sponge takes in or gives out water. This error was dispelled for all time by the masterly experiments of Count Rumford. He noticed that much heat appeared in the boring of cannon, and repeating the operation with care, he found that by applying mechanical motion indefinitely he could produce corresponding quantities of heat indefinitely. Plainly, what could be thus created at will could not be matter, and the equivalence of heat and mechanical motion was forever established. Lucretius, eighteen centuries before, had guessed that heat is nothing but the swift motion of the ultimate particles of bodies. But as only he discovers who proves, the credit of the mechanical theory of heat rests with Count Rumford.

Persuaded that heat is motion, physicists soon passed to the far-reaching conception that all other phases of energy, electricity and the rest, are also motion. An inquiry which at first concerned itself with only the thermometer as its instrument quickly demanded the fullest and utmost resources of the laboratory. Thanks to Meyer, Helmholtz, Joule, and Faraday, it was demonstrated beyond cavil that motion, like matter, may change its forms, but never its quantity; that, eternal in its essence, it can neither be made from nothing nor brought to naught; that, despite all its mutations, nature is but an infinite series of equations, no two of them different by so much as an atom or an atom's one gyration.

It is singular how a modern investigator will repeat an experiment that dates almost from the dawn of human skill, and discover a significance in it concealed until the hour of his interrogation. Ages ago the savage must have remarked that the hard work of grinding and polishing stone gave rise to heat. It remained for James Prescott Joule of Manchester, as recently as 1843, to carry forward by a decisive step the experiments which had begun with the savage and had been brought to a new meaning by Count Rumford. Joule set himself to find out exactly how much heat is equivalent to a given amount of work. He applied sinking weights to the agitation of water, and, taking elaborate precautions against the escape of heat, he found that 1390 pounds in descending one foot could raise the temperature of a pound of water by 1° C. Here at last was rendered an accurate account of the enormous debt due to the ability to kindle fire.

The Value of Fuels.

Wood, coal, and oil are among the most generous gifts of nature; without them not only would man be poorer in material possessions, but also in the skill and intelligence drawn out in the use of fuels. A pound of carbon is no bigger than one's fist, and yet, if all the heat it yields in burning could be applied to mechanical toil, it would do as much as a strong labourer in a week. To put it in another way, if all the energy contained in 2.8 ounces of carbon could be converted into work without waste, it would exert one horse-power for an hour. Every grain beyond 2.8 ounces that an engine demands for this service is a measure of its imperfection. No wonder, then, that when water- or wind-power is turned to the warming of a room, the cost is, as a rule, prohibitory. To get as much heat as would be thrown out from the contents of a common coal-scuttle, say 50 pounds in weight of carbon, would demand fifty horse-power for five hours and forty-two minutes. A prodigious reservoir of energy is unloosed trigger-fashion in the act of kindling a blaze, in the trifling labour of rubbing two sticks together, or striking a flint against a steel. A prehistoric smith by roundly hammering a bit of copper, or iron, on his anvil might warm it until it burned his fingers, while in a blaze the metal would not grow warm simply, but melt away. What Cyclops could wield a hammer with effect so violent? Plainly enough the capture of fire meant seizing a servant vastly more powerful than horse, or ox, or elephant, one that could be chained to tasks defying the might of either the winds or streams harnessed to the clacking mill-shafts of old-time industry.

The Kinetic Theory of Gases.

And this servant, heat, is as fruitfully studied in the molecule as in the mass. One of the most pregnant theories due to the study of heat offers an explanation of the pressure of gases or vapours confined in closed vessels. A thin, flat box containing but a pound of air can sustain, without the slightest hurt, a superincumbent atmospheric pressure of many tons. How? The molecules of the air, light though they are, bombard the inner sides of the box with so great a velocity (about 1600 feet a second) that the pressure from within exactly balances that from without. The speed of a projectile counts for as much as its density in creating its momentum—a tallow candle can be shot from a gun so as to pierce a thick oak plank. If we wish to confirm this kinetic theory of gases we are bidden to observe the rate at which common air rushes into a vacuum—we shall find it about 1600 feet a second. The inference is that the pressure of a gas, or a vapour, is at any instant represented by its actual motion through space. When, therefore, either steam or compressed air pushes a piston, there is nothing else done than giving up to the moving metal part of the projectile force from the gas. It is this parting with some of the motion in which heat consists that causes the temperature of the expanding substance to fall. We here observe one of the most important feats of engineering art—the conversion of heat into work.

Properties as Due to Motion.

The explanation of properties as due to actual motion has been extended far and wide beyond the bounds of thermal phenomena; it has become one of the fundamental conceptions of both physics and chemistry — now deemed but the higher branches of mechanics. It is thought, for example, that every whit of the stupendous energy developed by fuels as they combine with oxygen in flame actually resides as motion in them before they unite. This chemic motion is believed to be distinct from the heat motion represented by temperature, just as the movement of the earth round its axis is distinct from its circling round the sun. At extremely low temperatures chemical unions refuse to take place, so that it seems to be necessary to superadd thermal to chemical motion, if chemical affinity is to have free play. Let us observe a lump of coal as it lies quiescent in the mine and the atmospheric oxygen needed for its combustion; their chemic motion before their burning is held to be no more and no less than the visible and palpable motion which their flame would generate if applied without waste to doing work.

Sir Isaac Newton was so profound a thinker that even his guesses pointed to truth. As he observed the extraordinary refractive power of the diamond he conjectured that it was highly combustible. In due time the diamond was proved to be carbon, and was burned in one laboratory after another as thoroughly as if it had been so much charcoal. Newton's guess proceeded from his noticing that refractiveness, as a rule, characterised combustible bodies. It may be that this property is the betrayal of an unusual quantity of contained chemic motion—which impedes and turns aside an impinging beam of light. Enriched as the modern notion of the molecule has become, little marvel that the epithet "brute matter" is dropped from modern vocabularies.

The Probable Death of the Universe.

Investigators have not remained content with subtile inquiries regarding molecules. They have passed from the unit to the all—from studying the atom to considering the universe and its possible fate. In our survey of heat-engines we found that none of them converted heat into mechanical motion except with grievous waste. In truth heat is the form of energy hardest to convert into any other form; while electricity, chemical action, and mechanical motion easily and fully resolve themselves into heat. Heat by radiation, by convection, and by conduction ever tends to uniformity of temperature; but it is only when differences of temperature exist that there is an opportunity for the conversion of heat into work; just as every water-power in the world depends upon the difference of level between one part of a stream and another.

Suppose that in the morning of a summer day the thermometer stands at 30° C., and that we have at hand a pound of water at 0° C., and another pound of water at 60° C. We can get work out of both: the hot water may be used to expand air and drive a piston; the cold water may be employed to contract air and so move a piston in an opposite direction. But if, instead of doing this, we simply let the hot and cold water mingle together we shall have in a few seconds two pounds of water at 30° C., and no work whatever will have been performed, because the useful difference of temperature between the two pounds of water no longer exists. The ordinary temperature of the earth's surface is about 300° C. above absolute zero, and yet the vast store of heat thus represented is worthless as a source of work, for where shall an engineer find a lower temperature gratis with which he may chill the working substance of an engine?

With these plain facts before him, Professor William Thomson (now Lord Kelvin) nearly fifty years ago launched a speculation of the boldest. He reasoned that as the reservoir of unavailable heat in the universe is steadily gaining in quantity, it must eventually include all the working energy there is, and as matter at some indefinite future time will possess no other motion but that due to heat of high but uniform temperature, all further change will cease. In the present state of knowledge no flaw appears in the premises or deductions of this theory, and its sentence of death can be suspended only by the disclosure of countervailing processes as yet undetected. That such processes may yet be discovered is suggested by the question, If the theory be true, why, in the eternity of the past, did not the clock of the universe run down long ago?

That the "dissipation of energy," if real, is a slow process, is obvious from the marvellously sustained powers of the sun. Speculations as daring as they are ingenious have sought to account for the prodigious radiation of solar heat and light. It is estimated that to support this radiation from a single square foot of the sun's surface for one hour would demand the combustion of ten cubic feet of the densest coal. Upon what store of energy can drafts so prodigal be honoured year after year, age after age? The most plausible theory is that due to Helmholtz—that the sun's temperature is maintained chiefly by the contraction of his mass. It is a remarkable fact, first pointed out by J. Homer Lane of Washington, in 1870, that a gaseous sphere, losing heat by radiation and contracting by its own gravity, must rise in temperature and grow hotter until it ceases to be a "perfect" gas, either by beginning to liquefy, or by reaching a density at which the laws of "perfect" gases no longer hold. The kinetic energy developed by the shrinkage of a gaseous mass is more than enough to replace the loss of heat which caused the shrinkage. In the case of a liquid or solid mass this is not so.[1]

Are there Limits to Occupied Space?

Lord Kelvin asks whether the universe as a whole may not have limits in future time, and taste of death, as do its component moons, planets, and stars. Professor Simon Newcomb, the eminent astronomer, inquires whether the cosmos may not also have limits in the space which it occupies. He estimates that the number of stars revealed in the camera is perhaps 100,000,000. He asks: "Are all these stars only those which happen to be near us in a universe extending without end, or do they form a collection of stars outside of which is empty infinite space? In other words, has the universe a boundary?"[2] Let some yet bolder mathematician compute, if he can, the temperature which would result from the consolidation of all the matter of the known universe into a single ball.

In this realm of cosmical theories a remarkable contribution appeared from Professor F. W. Clarke, in the *Popular Science Monthly*, January, 1873. He drew attention to the fact that the hottest stars have the fewest elements in their spectra, and argued that as stars fall in temperature the increase in the number of their elements may be due to an evolution such as gives us chemical compounds on earth. This hypothesis has been ably maintained and developed by Sir Norman Lockyer, the astronomer. It offers an intelligible basis for one of the most significant laws known to the chemist. His "elements" have thus far resisted all available means of decomposition, but that they are really compounds is suspected from their falling into family

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[1] C. A. Young, *General Astronomy*, §356, 357. Dr. T. J. J. See, in the *Atlantic Monthly*, April, 1899, generalises the law of Lane.

[2] *McClure's Magazine*, July, 1899.

groups each characterised by kindred properties.[1] The stars glow at temperatures far exceeding those possible in the laboratory, so that in the stellar spheres a resolution of "elements" may take place such as the chemist cannot hope to repeat with any heat it is in his power to produce.

Fire and Religion.

While fire bears the richest suggestion to the philosopher of to-day, it meant much, also, to his ancestor, the priest. He saw that that great flame, the sun, was not only the quickener and sustainer of life, but its destroyer, too. At his altar there was propitiation as well as homage. Fire as a symbol in this august worship has glowed in lands widely remote from each other. The solar cult has had its temples in Egypt and Chaldea, in Greece and Mexico. Nor are fire-worshippers extinct. They notably survive in India, at Bombay. Of kin to them is the Japanese, who solemnly brings into his house at the new year fire which has been lighted by rubbing wood on an appointed day. The Russian, in the district of Tamboff, carries all the ashes he can and some stones from his old hearth into a new house, to bring luck—a survival of the transference of the fire itself.

Dr. D. G. Brinton says that all the American races, with the exception of the Eskimos, the North Athabascans, and a few others, have been sun-worshippers. The Comanches and Utes, for example, use the term "Father Sun," and perform dances and other rites in his honour. The Choctaws, who were devoted sun-worshippers, maintained perpetual fire, as did the Creeks. The Moquis of northeastern

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[1] The oxygen group, with the atomic weights of its elements, are: oxygen, 16; sulphur, 32; chromium, 52; selenium, 79; molybdenum, 96; tellurium, 125; tungsten, 183.6; uranium, 240. It will be noted that the figures which follow 16, the atomic weight of oxygen, are exactly or nearly multiples of 16. As an inference from the "periodic law," or, as one of its discoverers, Newlands, called it, the "law of octaves," the physical and chemical properties of an element are assumed to turn upon its atomic weight.

Arizona continue their worship of the sun to this day. The dates for the ceremonies of their calendar are determined by the position of the sun on the horizon.[1] In North America the tribal fires were political as well as religious: they shone not only upon priest and devotee, but upon chief and councillor. Here an order of precedence as strict as that of modern courts was observed; as foray and defence were planned, the seniors sat next the blaze, with the people around them, the juniors farthest from the hearth.

The founders of the cult of fire, Zoroaster and the rest, builded better than they knew. Every advance in science brings fresh perception that every throb of life around us has its mainspring in the sun. In entrapping a sunbeam, and releasing it ages afterward at a higher temperature, as rays from coal, the leaves of plants display a power to exalt the intensity of energy which is as mysterious to the philosopher as to the child. It is this postponed solar toil that we have been chiefly considering—a toil that has become of surpassing importance as the intelligence of man has grown from much to more. The savage may thrive with only the sun to work for him, but as he rises to barbarism he learns to kindle fire; while the empires of civilisation depend upon nothing more indispensably than their coal-mines, their naval coaling-stations dotting every sea. Was it a forefeeling of all this that bade the pagan recall in fire the infinite might of the solar blaze—that led him to discard for the pure and compelling flame the idols built from rock and tree?

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[1] Christianity, with its roots deep in the religions which went before it, bears a clear impress of the solar cult. Christmas falls immediately after the winter solstice, when the day beginning to gain upon night may symbolise the victory of good over evil. It is curious to note that the chief religious ceremony of the Moquis also occurs at the winter solstice. The second great festival of the Christian year reminds us that the moon once shared veneration with the sun. The Feast of the Resurrection takes place on the first Sunday after the first full moon on or next after March 21, the vernal equinox.

Myth Prefigures Fact.

In boyhood as one reads the myths of old they seem empty enough in meaning; not so when one takes them up in middle life. Were Briareus, with his hundred hands, and Argus, with his hundred eyes, anything but what the myth-maker himself desired to be? As he was opposed by mountains he wished to rend for his pathways, or by gulfs he would fain have bridged, he sighed at the feebleness of his bodily powers. Little wonder that he took comfort in imagining gods and heroes armed for tasks he so earnestly longed to perform, but which found him too puny for anything more than wishing. As man has come to more and more knowledge of nature, has grasped her forces with insight ever keener, the ancient dreams have come true, have been exceeded far. In days of old, when a ship moved through the sea against the wind, the sailor had to labour at an oar. To-day his hand is upon the rudder, not the oar; he has passed, like many a craftsman, from the lowly plane of immediate muscular exertion to the guiding of forces titanic in comparison with those of his own feeble frame.

Fire, in these modern times, has wrought blessings such as the ancients never dared to pray for. It has abolished much of the most exhausting drudgery known among men, as in building and mining. Upon people who count themselves poor it bestows an array of comforts in shelter, clothing, and food, in travel cheap and safe, which in the past fifty years have not only lengthened life, but made life better worth having while it lasts. Let us change a word in Shakespeare so as to have him say: "How oft the sight of means to do *good* deeds makes *good* deeds done!" If cruelty is disappearing from among civilised men, if Mercy widens her field with every passing year, if Hope sees new and assured ground for further betterment as one generation succeeds another, much must be credited to man's new ability to enjoy wholesome pleasures, to avoid pain and evil which were believed, until our day, to be as inevitable as doom. And in that new ability a leading place must be accorded the supersession of the hand and arm by flame, the application of fire to tasks impossible, and even unimagined, when the hand and arm were unseconded and alone in the field of toil.

It is a common remark that there is wealth enough in the world, were it only fairly apportioned. But let us remember that were the total yearly income of the American people, one of the richest on earth, allotted equally among its teeming millions, each share would be about two hundred dollars. Could this be called wealth? In truth, the world is poor, and while equity in distribution is desirable, not less desirable is it to increase the sum of divisible things by the untiring furtherance of knowledge at work.

A Scientific Philosophy.

Man owes to fire a yet weightier debt than either its industrial harvests or the physical theories which it has prompted. While as a thinker he has passed from fact to law, from detail to generalisation, his study of fire, of all that fire has brought in its train, has given breadth and depth to his philosophy. The more it has taught him of truth, the wider has it plumed the wings of his imagination for a secure flight into realms beyond the range of the eye. The savage, as he sought to explain what he saw around him, indulged in many a wild and baseless notion as to what lay beneath appearances. His fancies to-day are held but as the games and stories of childhood; the established theory of evolution peoples all space and all time with a procession of life, an involution of drama, that dwarfs and shrivels all purely invented story, all phantasms unrooted in fact. The cosmogonies of the cave and the wigwam have now little other interest than as chapters in the natural history of error, the first stumblings of the human mind in the long road which at last approaches truth. To-day the student of the universe looks *within* it, not *without* it, for the forces to explain its history. As his studies proceed he becomes more and more firmly convinced that nature is intelligible to her very core, that she has no laws which it is not his privilege and duty to know. In that order a tremendous part is played by the antithetical forces of Heat and Gravitation—Heat that sunders, and Gravitation that consolidates and unites.

Rich through all the ages of man's history as Fire was in itself, however lavish its gifts in woodland and mine, workshop and home, battle-field and temple, it was all the while a means no less than an end: it was preparing man to yoke to his chariot another servant as mighty—Electricity. Skill of hand with stick and stone entered a new kingdom when a spark of fire was created, preserved, and set to work; in its turn, fire made ready the way for conquests impossible to itself, as it brought man to the pitch of knowledge and skill needed for his new rôle as electrician.

CHAPTER VIII

THE PRODUCTION OF ELECTRICITY

THROUGH the course of all the ages since the first kindling of fire, almost down to our own day, flame had beside her a twin force all unrecognised. Now it glinted as lightning, anon as the aurora it streamed fitfully across the sky. It clothed itself in the amber of the sea-beach that, under gentle friction, drew to itself fragments of fallen leaves, of withered grass, or, in the hands of a comber, obliged tow and flax to fly apart as if in a lively breeze. Arrayed in iron it took on an iron constancy, unsupported masses defying the pull of gravitation for years together, and, as the legend tells us, sorely puzzling a shepherd by holding his crook fast to the ceiling of a cave roofed, as we would say now, with magnetic ore. Afloat in a bowl of water, the earliest recorded use of the lodestone is to point Chinese diviners to lucky sites for projected buildings; it was not until a much later time that the compass began to aid the mariner when sun and star were hidden. Little marvel that so various a masquerade was long impenetrable, that it should be only five generations ago that Franklin was able to identify the spark from the storm-cloud with the spark from his Leyden jar.

Unsuspected Kinship.

Between the first observations of flame and of electricity there is only contrast; flame, even while passively received, before the skill to kindle it had appeared, was recognised as useful. Electricity, on the other hand, was so fitful in its play, so slight in quantity, that no serious attention was ever paid to its phenomena until comparatively recent times. Not until the eighteenth century was it suspected that the tiny sparks due to common friction were of identical character with the dreaded lightning of the sky. The conductor devised by Franklin for the protection of buildings is first in the order of time among useful electrical inventions, just as the compass is first among magnetic contrivances.

Four Great Pioneers.

The experiments of Franklin were possible in that he was rich by inheritance from an illustrious line of investigators, of whom four stand out so pre-eminently as to divide honours with their great successor. These four are William Gilbert, Otto von Guericke, Stephen Gray, and Dean von Kleist. Their labours did much toward opening the path which should end at last in creating a force by turns an ally or a rival to fire itself; they showed (1) how electricity could be produced in quantities comparatively large, and with new facility; (2) how a charge could be insulated and so preserved from dissipation; (3) that such a charge was transmissible for long distances with but little loss, and with seeming instantaneity; (4) that electricity could be excited in an uncharged body as it approached a charged body, by just the same induction that excites magnetism in common iron as it comes near a compass.

Gilbert, who was court physician to Queen Elizabeth, began his studies of electricity by an elaborate investigation of the properties of the magnet. Poising a light, metallic needle compass-fashion, he was able to measure the attractive force in the various substances which he excited electrically and brought near this first of all electrical instruments (Fig. 22). He discovered that there are many substances, like amber and jet, which, when electrified by friction, exert attraction; of these substances he drew up a useful list. He ascertained, also, that the substances which refuse to be electrified by friction are not few, but many. This class he named non-electrics, including among them the lodestone, silver, gold, copper, and common iron; all these were to be grouped at a later day as conductors, to be distinguished from the non-conductors which Gilbert called electrics. His means of examination were inadequate to the proof that conduction is a universal property of matter, and that all the difference between copper and glass in this respect is that they occupy the two extremes of a single scale. In the vast difference between the conductivity of copper and of glass lay the possibility, soon to be realised, of sending electricity afar by giving it an easy path of travel, a path hedged in by a covering through which the charge could not escape. Gilbert discovered that a piece of silk laid upon an electric directly after friction preserved a charge of electricity. This was of cardinal importance, for now such a charge could be preserved as had never before been possible. He noted, too, that the transmission of electricity seemed to be instantaneous.[1]

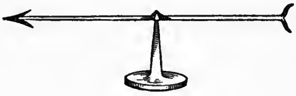

FIG. 22.
Gilbert's electroscope.

Otto von Guericke, the famous burgomaster of Magdeburg, who flourished about the middle of the seventeenth century, devised the first machine for the production of electricity. This was simply a ball of brimstone turned on an axle, against which silk and cloth were firmly held

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[1] An account of Gilbert's achievements, which included much else of moment, is given in *The Intellectual Rise in Electricity*, by Park Benjamin. New York, Appleton, 1895.

(Fig. 23). The device marks the entrance of electricity as a creation of mechanical power on a scale impossible to the friction of handkerchiefs on glass. It brought out the fact, too, for those who cared to think about it as they turned the handle of the apparatus, that the generation of electricity meant hard work, and that the attractions or repulsions which resulted from the machine's operation were no other than the reappearance of this work. Von Guericke's crude device was succeeded by a bottle-shaped cylinder of glass; next came the circular glass plate whose sparks were caught on metallic teeth and borne away to work their wonders. Von Guericke, by varying the form of a conductor, came upon a discovery of prime importance. Instead of using a mass of metal of the usual compact form, he employed a linen thread, an ell or more in length; he found that the electric charge traversed it in a twinkling. He thus extended and confirmed the observation of Gilbert as to the speed of electricity.

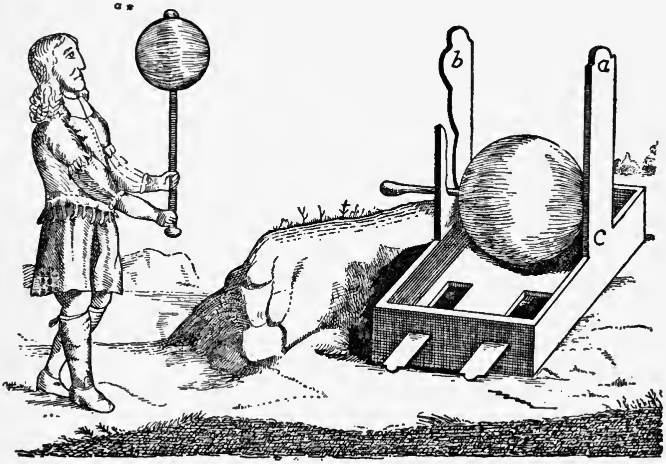

FIG. 23.
Von Guericke's first electrical machine.

Stephen Gray, a pensioner in the Charterhouse of London, in 1728 and thereabout carried forward the work of Von Guericke in a masterly way. He observed that even very short pieces of silk were impervious to electricity, so that with silk as his insulator he succeeded in conveying an electric charge through a metallic wire for a distance of more than three hundred feet. Here was the first practical use of an insulator as a means of promoting the transmission of a charge to a long distance. Gray discovered, furthermore, that his electrified glass tube affected his line without contact—by induction, as in the case of bits of foil observed long before by himself and his predecessors. Next to Gray in this early roll of honour stands Dean von Kleist, of the Cathedral of Camin in Pomerania, who, in 1745, invented the original form of Leyden jar. This was simply a vial in which a nail, or bunch of wire, was charged with electricity; protected by the non-conducting glass, the inclosed metal maintained its charge for a comparatively long period.

It was by such steps as these, humble and tardy as they were, that electricity began to take its place beside fire as one of the supreme resources of man. He had now discovered how he could best generate it by a wise choice of substances to be rubbed together; he had learned to discriminate between things which convey electricity very well and very badly; he came to know how, by the use of bad conductors or non-conductors, a charge might be preserved from the almost immediate dissipation that followed every old-time experiment; and, above all else, he had found that electricity has a pace so rapid that it seemed instantaneous.

The electricity of the frictional machine was now easily stored for as much as an hour at a time, and the range of electrical experiment passed from the laboratory of the student to the drawing-room of fashion. Experiments familiar to us all from childhood excited interest throughout wide circles of the learned and the uninformed. Pithballs charged with positive or negative electricity were suspended to repel each other just as the north or the south poles of two magnets drove each other away. Then, to balance marvel with marvel, two strips of gold-leaf, when oppositely electrified, sprang together as eagerly as the north pole of one magnet seeks the south pole of another (Fig. 24). Here was a clear intimation as to the identity of electricity and magnetism which led in due season to the best modern means of producing them both.

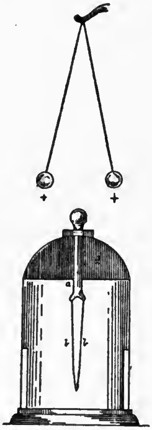

FIG. 24.
Electrical repulsion and attraction.

Thus far the generation of electricity had no practical worth. Its attraction and its sparks were too feeble to be more than curious, for the moment the operator's hand ceased to turn the axle of a machine all electrical phenomena vanished. As compared with the first fire-making this early production of electricity was much more artificial, but it was not artificial enough. To rub a globe or disc of glass with a silk handkerchief is certainly a farther reach of artifice than to abrade one stick against another, or to strike together two pieces of iron pyrites. Yet, when the firemaker brought his spark or smouldering dust to fuel, his labour was not only immensely heightened in effect, but carried on indefinitely, and this without another blow or thrust from his arm. There was wanting a similar step in electric art: it was necessary that for a time the chemists should bow the mechanics off the stage.

As early as the fifth century it was recorded by the Greek historian, Zosimus, that iron swords plunged into copper solutions came out coated with a film of copper. This observation, like that of the first lodestone, came too soon to bear fruit at once. It was not until 1759 that

Volta Invents the Pile and the Crown of Cups.

Galvani noticed that a metal wire touching at one end the nerves of a frog, and at the other end the muscles of its leg, caused a momentary twitching. When he used two wires of different metals the contractions were much more vigorous (Fig. 25). As he found the same convulsive movement followed from the spark of a frictional machine, he concluded that the phenomena had a common origin in the animal itself. Volta took the next step; he reasoned that the electrical energy was due rather to the action of the wires than to any property of the frog's flesh. Following this train of thought, he built up a series of zinc and silver discs, separating each disc by cloth moistened in acidulated water; from this "pile" he obtained electricity in the form of a flow, much more satisfactory than had ever been evolved from a frictional apparatus (Fig. 26).

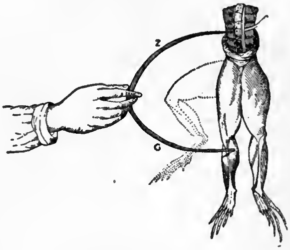

FIG. 25.
Galvani's experiment.

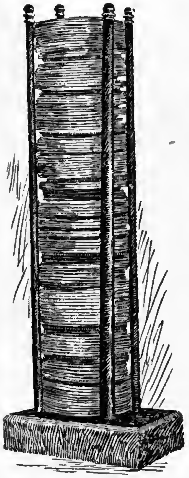

FIG. 26.
Volta's pile.

For the first time in human art electricity now poured forth in the absence of toil; here was just such an advance as that of obtaining heat from fuel instead of from muscular exertion: the feat of starting a blaze which continues itself and leaves its kindler free had found its parallel. Before Volta a charge of electricity was no more than could be excited by rubbing one surface on another; he invoked the might of chemical forces which involve masses instead. As each disc of zinc dissolved in his pile it presented a rapid

PLATE II.

ALESSANDRO VOLTA.

succession of new surfaces to the intense affinity of the corroding liquid. Before the time of the great Italian's device, electricity was little more than a curiosity, an actuator of toys, instructive if you will, but toys nevertheless. As soon as the voltaic pile was constructed electricity was no longer something to stare at, but a force to work with —a servant to take orders of the most exacting kind and execute them with fidelity.

As Volta built his experimental pile higher and higher, he found it more and more faulty, for the moisture was harmfully squeezed from the lower pieces of the acid-holding cloth. In 1800 he abandoned it and devised the "crown of cups," a battery of the simplest type and the parent of every battery since fabricated; each cell contained a plate of zinc and a plate of silver immersed in an acid solution. The current now obtained, though uneven, had the character of a flow from a reservoir, at low pressures to be sure, but in quantity vastly greater than the discharge from a frictional machine, and without the bolt-like and unbiddable quality of the machine spark. When voltaic cells as a series were joined as the links of a chain, the zinc plate of one cup attached by a wire to the silver plate of the adjoining cup, each exalted the intensity of the next, and there was a distinct approach to the lightning tension of the original apparatus built of glass (Fig. 27). For generations the sole incentive to electrical inquiry had been philosophic curiosity—the desire to know, not the desire to profit. The moment that Volta disposed his crown of cups this disinterested quest came to a great reward: a new agent was brought under easy control—an agent of powers known to be remarkable, of qualities surmised to be transcendent.

A link between the old servant, heat, and the new candidate for employment, electricity, was soon discerned. It had long been observed that a metal as it dissolved in an acid solution underwent a rusting process accompanied by a rise of temperature. Fabrioni in Italy, and Wollaston and Davy in England, now pointed out that the zinc in a battery rusted away without any evolution of heat whatever. It remained for Faraday some years afterward to identify the heat which zinc may yield, as it corrodes by itself in an acid bath, with the electricity it may evolve in a voltaic cell, and to prove that in terms of energy the two are the same. The failure of the voltaic battery to produce electricity at a low price turns upon the fact that even if the zinc cost no more per ton than coal, it has but one-seventh the fuel or energy value; furthermore, coal employs air without cost to form its compounds, while zinc demands expensive acids. We shall presently see how coal is indirectly employed, through the steam-engine, to produce electricity, and with an economy which restricts the voltaic battery to a minor range of utilities.

The Thermo-battery.

There is an alliance of heat with electricity which is immediate, and dispenses with the roundabout processes of the steam-engineer. Heat from coal and other fuels may be directly applied to generate a current, although with a waste so enormous as to be prohibitory. The pioneer in this field was Seebeck, who in 1822 showed that when heat is applied at the junction of two different metals an electric current is created. Subsequent trials on a comprehensive scale proved that antimony and bismuth form the best pair for this effect. Notwithstanding many attempts at its improvement, the thermo-electric battery remains unsatisfactory. Its pairs are apt to break apart by inequalities of expansion and contraction, and the metals employed lose efficiency from causes referable to molecular change.

A thermo-battery that would be simple, compact, not liable to get out of order, and of moderate cost, would have wide acceptance; for although but an extremely small part of the heat sent through it might be converted into electricity, that fraction would be clear gain in many cases. Very often heat is required only for warming, and air or water after it had passed through a thermo-battery would be at a temperature quite high enough for this purpose. While the thermo-battery has developed no industrial value as a source of current, it has become in the laboratory an exquisitely delicate means of detecting minute quantities of heat. An electrical thermometer invented by Professor Callender is accurate to $\frac{1}{10000}$ of 1° C. The means of this detection depend upon the discovery of the kinship of magnetism and electricity, and this brings us to the phase of electrical art which has the highest practical importance.

The Unity of Electricity and Magnetism Detected.

When early investigators saw electrified bits of foil attract and repel each other as if they were magnets, they began to ask, Is there anything in common between the smiting together of morsels of gold-leaf oppositely electrified, and the clashing of steel oppositely magnetised? Örsted answered this question in 1820, as he deflected a compass-needle, *ab*, by a wire, *NS*, conveying a current (Fig. 28). Ampère, in a series of conclusive experiments, further explored the relations between magnetism and electricity. He showed that wires bearing currents attract or repel each other just as magnets do. His most telling demonstration was the poising of a coil of wire, compass-fashion, so as to permit the utmost freedom of movement; when a current was sent through this coil it took up a north-and-south position, attracted iron tacks and filings, and attracted or

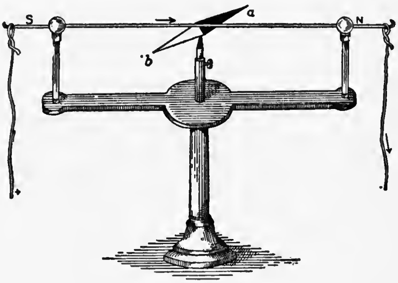

FIG. 28.
Örsted's experiment.

repelled a steel magnet precisely as if it were a magnet itself (Fig. 29). The inference was clear—a steel magnet may be considered as a coil, or spiral, affected by electricity in rotation.

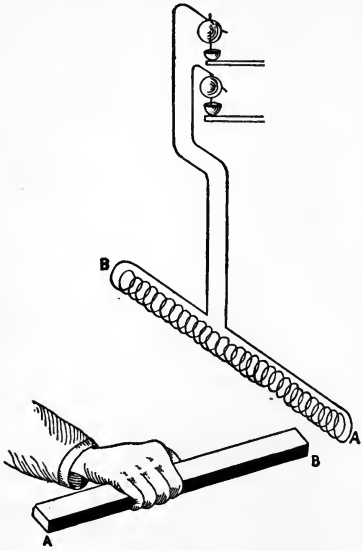

FIG. 29.
Electric solenoid pole (*A*) attracted by dissimilar pole (*B*) of bar magnet.

One contrast, however, was evident from the first—the moment that a current through a coil ceases, its magnetism vanishes, while the attractive power of a steel magnet may be maintained for years. Around every magnet is a space, or "field," through which it exerts influence in a manner easily brought to view. We have only to strew iron filings on a sheet of paper close to the pole of a magnet, and a few gentle taps will cause the filings to stand out in radial lines (Fig. 30). If we take the same paper, and, removing the magnet, pierce the sheet with a fine wire conveying an electric current, the filings will now dispose themselves in concentric curves instead of in radial lines (Fig. 31).

Sturgeon, in 1824, advanced matters by an important step as he discriminated between the magnetism of steel and that of soft iron. He noticed that soft iron was magnetic only while in contact with a steel magnet; when he severed them the soft iron at once lost its attractive power. He found also that if a core of soft iron was placed within an electrical coil, the iron instantly became a magnet of uncommon strength; and that the moment

PLATE III. *From a photograph by Maul & Fox, London.*

MICHAEL FARADAY.

(Holding a bar of heavy glass.)

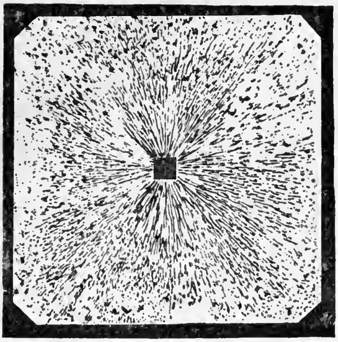

FIG. 30.
Magnetic lines of force.

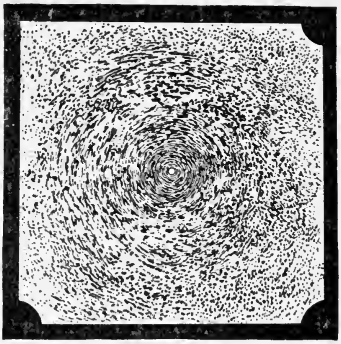

FIG. 31.
Electric lines of force.

the current was broken the magnetism of the iron disappeared (Fig. 32).

Professor Joseph Henry, in researches conducted from 1828 to 1830, much improved Sturgeon's device. That inventor had wound but one coil of copper wire around his magnet, using varnish on the iron as a means of insulation. Henry insulated a long wire with silk thread, and wound this around the iron in several close coils, obtaining a much more powerful effect than Sturgeon's (Fig. 33). In this temporary magnet, or electromagnet, as thus improved, lay a gift to science and art incomparably more valuable than the permanent steel magnet could ever be. In America, from the beginning of electric telegraphy until now, an electromagnet has been the indispensable heart of the apparatus. A momentary current from a distant station is received in a coil of copper wire; that instant its soft iron core

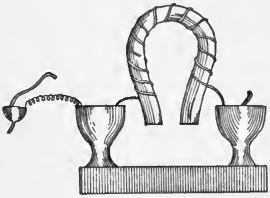

FIG. 32.
Sturgeon's electromagnet.

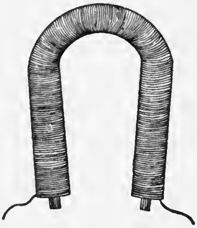

FIG. 33.
Henry's electromagnet.

becomes a magnet, and in attracting its armature gives a signal.

The Dynamo is Born.

If electricity was ever to take its place beside fire as a servant of equal or superior value, it was imperative that an electric current should be generated at low cost. Here the voltaic- and the thermo-batteries had failed; both chemical and direct thermal action proved to be too expensive for any but limited uses. There remained but one avenue in which hope lay of a current cheap enough to be used as freely as flame—perchance, indeed, as its supplanter. Electricity in large quantity and at a low price is a boon due to the electromagnet, which is essential not only to the telegraph, but to the dynamo and motor as well. It is these devices that have taken electricity from the seclusion of the laboratory to the engine-rooms and workshops of the world. Both the dynamo and motor sprang from the investigations of Faraday in 1831, as he repeated and extended the inquiries of Örsted. It had long been known that a steel magnet induces magnetism in a soft iron mass as they approach each other, and in a degree determined by the proximity of the two. Faraday discovered that the like is true in the province of electricity. "Let there be two copper wires," said he, "parallel to and near each other. Send a current through the first and a momentary current is induced in the second (Fig. 34). Vary the quantity of the primary current, or break it off completely, and at once there is a response in the secondary wire."

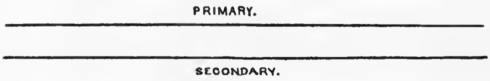

FIG. 34.
Electrical induction.

He then extended his researches to the ties which bind magnetism and electricity. Örsted had observed that an electric current produces motion in an adjacent magnet

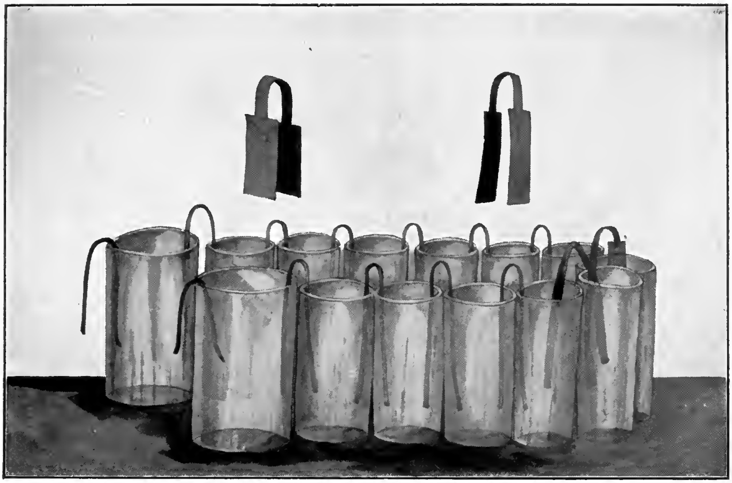

FIG. 27.
Volta's crown of cups.

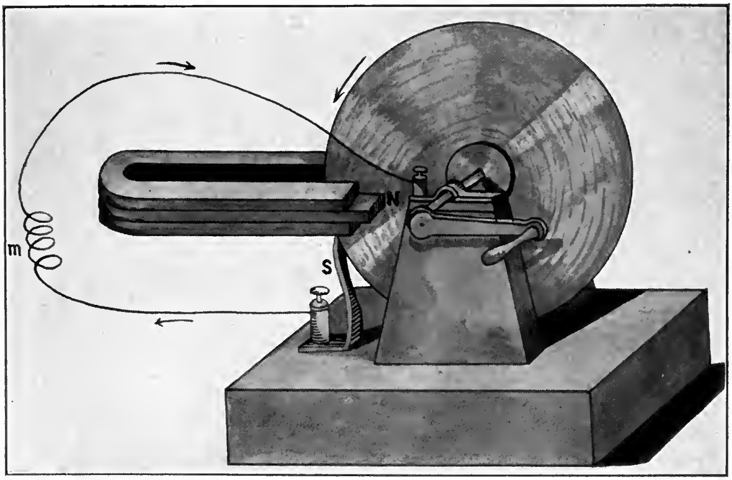

FIG. 35.
Faraday's magneto-electric machine.

nicely poised. Faraday developed the converse truth—that a magnet moved near a conductor induces a current therein. That here was a means of generating electricity by mechanical means he at once proceeded to show. A disc of copper a foot in diameter, and about a fifth of an inch in thickness, was fastened in a frame so as to be easily turned by a handle, the edge of the metal lying between and close to the poles of a large permanent magnet (Fig. 35). Two conducting wires were applied to the disc, one at its rim, *S*, the other at its axle, *N;* these bore away the current generated as the disc was turned. Here, as in all similar cases, the motion of a conductor in the field of a magnet created a stream of electricity equal in energy-value to the mechanical exertion expended. Faraday's apparatus, simple as it is in form, is the parent of every dynamo since constructed; and because mechanical power is vastly cheaper than chemical energy we have to thank him for emancipating electricity as an agent for common, every-day tasks—some of them, indeed, once within the exclusive province of fire itself.

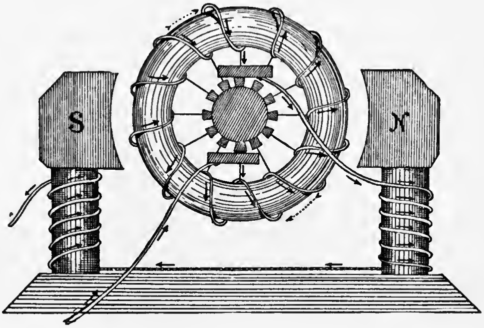

Fig. 36.
Gramme Machine.

In embodying Faraday's discovery in a machine of the best design, the first step was taken when Dr. Pacinotti, of the University of Pisa, in 1860 shaped an armature into the form of a ring. Gramme, about eleven years later, invented a machine in which this ring armature formed the chief feature. Fig. 36 shows this machine as a simplified skeleton. As rotated between the magnetic poles, *N* and

S, a current is generated in the wire surrounding the ring, which current is carried off by the wires shown just within the ring.

We should note in passing that Faraday's model is capable of rotation if a current be applied at its rim and axle; in other words, the machine is perfectly reversible and may be used as a motor if a current is required to yield mechanical power. The motors which to-day furnish power from currents on a large commercial scale are little else than dynamos reversed, yet the reversal, obvious as it seems now, was not adopted until 1873, although it was known to Jacobi in 1850, and probably to Lenz twelve years before. In 1873 several Gramme dynamos were to be shown at the Vienna Exposition. A workman, seeing a pair of loose wires near one of the machines, connected them with it; the other ends of the wires proved to be bound to a dynamo in full rotation, its source of power being a steam-engine near by. The second and newly attached machine at once began to revolve in a reverse direction—as a motor. Thus, in all likelihood by sheer accident, it was discovered that one dynamo may yield in mechanical power the electric energy sent to it from another dynamo at a distance. In the whole realm of industrial art there is no more striking example than this of a rule that works both ways.

In its developed form the electric motor is somewhat modified from the dynamo in model; both of them in their latest and best designs come short of perfect efficiency by only 2½ per cent. Using a steam-engine or a water-wheel as its prime mover, the dynamo is much the cheapest means of producing electricity, supplanting, for all but inconsiderable uses, the primary chemical cell invented by Volta.

Having cast a hasty glance at the principal steps in obtaining a current with more and more economy, let us begin a rapid survey of its applications, first of all taking up those where its heat is turned to account, in singular rivalry with fire.

But before we pass on it behooves us to note how strictly the ablest men are the children of their own day, with all its limitations of horizon. Among English physicists the greatest since Newton is Dr. Thomas Young. In 1807, thirteen years before the decisive discovery by Örsted, Dr. Young wrote: "There is no reason to imagine any immediate connection between electricity and magnetism, except that electricity affects the conducting powers of iron or steel for magnetism in the same manner as heat or agitation."[1]

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[1] *Lectures on Natural Philosophy*, London edition, 1845, Vol. I, p. 538.

CHAPTER IX

ELECTRIC HEAT

From the Miner's Fuse to the Forge and Weld.

THERE are many cases where a task of so much moment is performed by a little heat that its cost need not be considered. Hence we find that long before electric currents were cheapened by the dynamo there was noteworthy employment of the high temperatures born of electricity. In early experiments these temperatures were observed as a conducting wire was narrowed in diameter. When for an inch or two it was reduced to extreme fineness, it could there be fused by a current as by a furnace breath, through increased local resistance. The molten drops betrayed as they fell that the new agent, electricity, was no other than the old servant, heat, in an easily discarded dress. The miner had long been vexed by the uncertainty and hazard of fuses lighted by common fire, both dampness and rupture contributing to the frequency of serious hurt and damage. With electric heat led into a fine wire he could now fire a fuse with perfect safety at any distance he pleased, and blast a rock at as many points as he chose all at the same moment, with an effect otherwise impossible.

The gunner soon learned the miner's lesson. In a battle at sea a whole broadside may be directed upon a single turret of the enemy's fleet, and fired with a destructiveness new in the art of war. If the gun-decks of a cruiser are so enveloped in smoke that the foe cannot be seen by the men at the guns, the firing may be directed by an officer far enough away to be in clear air. In like manner the submarine mines and the torpedoes impressed into defence, or attack, are exploded at the commander's nod by a telegraph-key a mile or two off. The surgeon, who is never far away when the gunner and torpedo crew are busy, is equally served by electric heat, employing it as he does for a delicate cautery.

In the arts of peace electric heat, even at comparatively low temperatures, is widely useful since its cheap production by the dynamo. A current of dangerously high tension may sometimes by accident enter an instrument or machine; but if in the gateway it must traverse a strip of lead and tin alloy, the metal will melt away, and the current thus interrupted can do no harm. When severe frost has frozen a water-pipe an electric current warms the metal and thaws the ice much more quickly and conveniently than flame. In the manufacture of fine varnishes, in the reduction of sulphide nickel ores, in tempering metals, it is necessary to maintain a certain temperature and guard against its slightest increase; in all such tasks the easily regulated heat of electric origin leaves nothing to be desired. The manufacture of felt hats requires a sustained heat at definite temperatures; this is supplied much more satisfactorily by electric coils than by gas-flames.

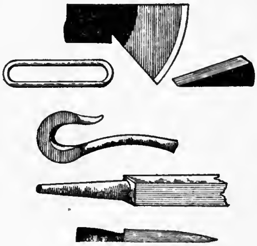

FIG. 37.
Metal shaped under electric heat.

Metal-workers adopt electric heat with peculiar gain. When a strip or tube of iron, copper, or brass is to be bent, twisted, coiled, or hammered, the work is easy if the metal is first softened by electric heat. Hooks, links, axes, and other tools are formed as readily as if in wax (Fig. 37). In this branch of industry the expert may excite the onlooker's wonder by tying a knot in a stout rod of steel as if he were manipulating a yard or two of rope. A new electric machine brings a rivet to redness, and, just before it might melt, secures it in place by extreme pressure.

Temperatures higher still open the way to the electric welder. The flame of a forge or a furnace is often difficult to apply, especially when large masses of metal have to be treated. Let two pieces of metal, however large and irregular in form, be forced together within the clamps of an Elihu Thomson machine, and at their point of contact a welding heat is developed precisely where it is wanted. When the broken blade of a steamship's propeller is to be repaired, or the standing rigging of a ship is to be united, or the rails of a street-railroad are to become a continuous line of metal, the electric welder can be taken to its work instead of the work having to go to a stationary welder.

Within the walls of a factory this appliance is quite as useful and even more versatile. It joins the tires of bicycles, carriages, and wagons; it unites tubes, pipes, barrels, and band-saws; for the telegraph and the telephone it supersedes the old and imperfect splicing by a joint and so enables lines of direct communication to be much longer than before (Fig. 38). In lumber-mills it resets a tooth accidentally torn from a saw, and rarely does the metal ever part again at the same point of stress. In the service of war it binds a tip of hardened metal to the soft case of a shrapnel shell, and forms into a single mass the ponderous anchor of a flag-ship. All this gain in convenience and cleanliness, accessibility and economy, arises from having intense heat without flame, and from being able to apply it at

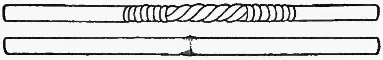

FIG. 38.
The old weld and the new.

one particular point and no other. As a consequence, fire is dispossessed from many tasks which until our day it was believed that only fire could perform. Another supplanting of the ancient work of flame is due to the fact that its temperatures are far outdistanced by those of electricity.

The Arc's Fierce Heat.

The electric arc as we see it glowing in the thoroughfares of cities has much the appearance of exceedingly brilliant flame. The Bernardos process uses this arc for metal-working with excellent results. A rod of carbon in an operator's hand forms one pole of the circuit, the metal to be softened or melted forms the other pole. In the Slawianoff method, a metal rod forms the second pole; as its molten drops fall upon the surface to be welded, the effect is usually preferable to that of Bernardos. Both plans are extensively employed in the repair-shops of the Russian government railroads. The harveyised steel for armour-plates is so hard as to resist drilling for the insertion of its bolts; the electric arc in a moment reduces the metal to plasticity at the point where the drill is to perform its duty. A boiler-plate ruptured by accident is fused like wax by treatment of a little longer duration, while sheet metal is cut away as if it were so much paper. Brazing, even on a large scale, is accomplished with celerity and cleanliness. Were it not for the blinding glare of the arc these uses of it would be less uncommon than they are.

In the Kroll process of glass-making, recently tested at Cologne, an electric arc replaces flame with manifold advantages. The materials are fused in fifteen minutes instead of in thirty hours; two-fifths of the fuel is saved; there is no risk of dirt or ashes falling into the glass; and on Sundays and holidays work may be stopped with no loss whatever, as there are no bulky and expensive furnaces to be cooled down.

As a rule water quenches fire. What shall we say when we see a bar of cold iron dipped into a bath of water and quickly rise to a white heat? The mystery is solved when we observe that one pole of a powerful battery or dynamo is connected with the bar, while the other pole is attached to the lead lining of the bath. The water as decomposed by the current deposits a film of hydrogen on the surface of the iron, and the high resistance of the gas gives rise to so intense a heat as virtually to create an electric arc. This arc, always unquenchable by water, rapidly raises the metal to a very high temperature. Sal-soda is added to the liquid so as to improve its conduction of the current; borax also is dissolved in liberal quantities to remove any oxide which may be formed (Fig. 39).

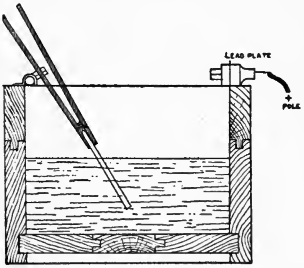

FIG. 39.
Water-tank electric forge.

Beyond the temperatures suited to welding, glass-making, or forging, the electric arc produces heat more intense than any other at the chemist's disposal (Fig. 40). This heat is preferable to that of flame in that it can be carried into a crucible through almost impermeable walls of chalk or gypsum, so as to be free from the loss by radiation inevitable to a blaze. When a molten core of metal is surrounded by a cake of ore of low conductivity, temperatures may be reached, and effects produced, impossible to crucibles heated from outside.

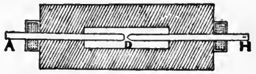

FIG. 40.
Electric furnace.
A and *H*, carbon electrodes; *D*, arc.

Carborundum is one of the recent creations of the electric crucible. This compound of carbon and silicon ranks next to the diamond in hardness, and has, therefore, high value as an abrasive. Its vitrified grinding-wheels employ porcelain as a bond; a little iron effects direct union between the porcelain and the carborundum particles; they cut the hardest steel so quickly as not to case-harden or draw the temper of a tool, the metal is brought to an edge before it has time to be heated. Carborundum has a wide variety of other uses: it grinds and polishes granite; it turns out steel balls for bicycle and other bearings; it makes the rolls through which pulp is squeezed in paper-mills, it smooths the biscuit-ware in potteries. This new substitute for emery and corundum is manufactured at Niagara Falls on a huge scale from coke, sand, salt, and sawdust, materials strangely different from their offspring. When one-half of 1 per cent. of carborundum is added to steel, the metal becomes more fluid and ductile, with escape from the risks of honeycomb. Mr. E. G. Acheson, who invented the carborundum furnace, has recently adapted electric temperatures to the production of graphite from bituminous coal. Graphite as a product of the mine has long been used for pencils, for crucibles, and as a lubricant. The carbons employed by the chemist as his electrodes in the manufacture of alkalis and other compounds, and by the engineer for his dynamo- and motor-brushes, are lengthened in life many times when graphitised by the Acheson method. Another product of electric heat which is fast rising into commercial importance is carbide of calcium, manufactured from quick-lime and coke. When placed in water, this compound sets free acetylene, a gas of high illuminating power, rich in photographic rays.

Professor Henri Moissan, in his electric furnace, has brought forth a series of perfectly crystallised compounds, borides, silicides, and carbides of metals which, from their demand for the fiercest natal heat, are believed to represent the foundation-stones of our planet. Compounds, such as those of chromium and tungsten, of a refractoriness which defies every other furnace, are readily separated by Professor Moissan in his electric crucibles, while silicon and carbon are volatilised, and lime, zirconia, and silica are sublimed without difficulty. In the reduction of highly resistant compounds recourse is had, as in the case of fire, to the presence of carbon, which, by its intense affinity for oxygen, promotes the chemical separation.

As M. Moissan one day pondered the fact that small diamonds are sometimes found in meteoric iron, he asked, Can their creation in similar metal be repeated? He reasoned that the meteorite had probably sustained great pressure as well as a high temperature, and that both conjoined had given birth to these little gems. He endeavoured to recall in the laboratory what had probably occurred in the history of the aerolite. Boiling a crucible of iron in his electric furnace, he dropped into the seething mass a goodly lump of carbon in the form of coke; it was dissolved as greedily as sugar is by hot tea. He then placed masses of the molten mixture in cold water; suddenly shrunken as they were, an intense pressure was exerted by the outer part of each mass upon its core. When all had cooled down he had succeeded in making some minute diamonds; the path of nature in the production of the gems of the mine had been clearly retraced. Fortunately for the owners of such mines, the electric method has not yet produced any stones large enough to be precious in a commercial sense.

M. Moissan has further devised a plan for separating calcium from its compounds, which may have an important bearing upon agriculture. He finds that calcium enters readily into combination with nitrogen, and that from the nitride so formed it is easy to make ammonia. If conducted on a scale sufficiently large, this process of the laboratory may pass to the manufactory, and prove cheap enough to supersede all other modes of obtaining a capital fertiliser.

The intense flame of the blowpipe, so readily directed hither and thither, has its counterpart in an electrical device due, in its original form, to Dr. Zorener of Berlin. He noticed that an electric arc can be deflected by a strong magnet much as a common blowpipe responds to the breath. In Fig. 41 an electromagnet *D* pushes out, as if by a light breeze, the arc formed between the two carbon poles *B* and *C*. Lieutenant Jarvis Patton draws attention to the perfect control of an arc which such an electromagnet affords. When an arc has fused part of a metallic charge in a crucible or furnace, it has diminished, by aggregation, the resistance of that particular portion of the whole mass, and because its path just there is freer than elsewhere it continues to traverse it idly and uselessly. Directed by a magnet, the arc may now be shifted to fresh surfaces of material where its action is most required.[1]

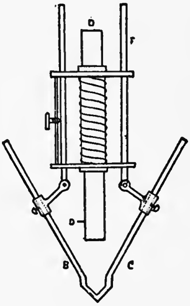

FIG. 41.
Electric blowpipe.

When the metallurgist dismisses flame in favour of electric heat an old annoyance takes its departure. Castings made in the ordinary way are exposed to the air and often contain blow-holes, while they lack homogeneity and sharpness. When the metals are fused and cast by electricity in a vacuum, these defects disappear and a new perfection both of substance and surface is attained.

A Twofold Disjoiner.

Electricity has a parting power which it retains in the presence of heat, even of heat which it may itself have created; electricity, therefore, when added to heat, hands the chemist a two-edged sword of irresistible cleaving might. Armed with it, he disjoins fused salts as a flourishing industry, so that elements once rare and costly are marketed at prices low and steadily falling. Aluminium,

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[1] *Electrical World*, October 22, 1898.

discovered by Wöhler in 1828, was for fifty years so scarce and dear as to be formed into jewellery; to-day the metal is cheap enough to find a ready sale as kitchen ware. Other metals and metalloids now surrendering themselves to the joint attack of heat and electricity are nickel, sodium, phosphorus, and glucinum. The last-named of these, glucinum, or beryllium, has remarkable qualities. It is lighter than aluminium, is not oxidised in any ordinary exposure, while its electrical conductivity exceeds that of copper. If its production should be constantly cheapened, as has been the case with aluminium, this valuable metal would find extensive employment in the arts.

As with elements, so with compounds of equal industrial importance. In the Acker process now employed at Niagara Falls, caustic soda is obtained from a molten electrolyte instead of from a solution of ordinary temperature. The current required is greater than where brine is decomposed, because the electrolyte is kept in a molten state by the very current which also decomposes it. But this additional cost is more than offset by the fact that the caustic soda is obtained directly in an anhydrous state ready for the market, obviating the evaporating and boiling-down process heretofore essential.

The Field for Conquest.

Useful as electric heat is to the metal-worker and the chemist, may it not be equally so to that large public who employ heat in every-day tasks of warming and cooking? To answer this question, let us approach an electrolier bearing upon its branches twelve incandescent lamps, each of sixteen-candle power, such as are usually employed at a desk or in a workshop. To supply these lamps with current one horse-power is being consumed at the central lighting-station near by, and yet as one holds one's hand above the bulbs their warming effect is no greater than if three or four ordinary candles were alight.

In applying heat to the generation of mechanical power we have already noted how serious are the wastes. In the very highest efficiency on record the losses are nearly 80 per cent.; in ordinary cases they exceed 90 per cent. When this large deduction is taken into account it is clear that, except for minor uses, the employment of electricity for warming and cooking is usually quite out of the question. To warm a street-car by electricity is economical because the car is of dimensions so contracted that but little heat suffices, while the space a stove would occupy is left free to hold a passenger. In cooking for an invalid, where slight extra cost need not be considered, electricity answers better than fire. One of the theatres in London has been warmed by electricity since 1894; its auditorium is small, and a comparatively slight rise in temperature is enough for the needs of an English winter.

Where electricity can be produced very cheaply by water-power, we are shown what may be expected from a current should it ever be as cheaply derived from coal. At the Carmelite Hospice, on the Canadian side of Niagara Falls, a current of seventy-five horse-power is bought for heating purposes at a rate equal to but $5 a year per horse-power. In winter, when heating is in request, the dynamos are not in demand for the railroad work which occupies them in summer.

Electric heat, as here supplied, is incomparably superior to flame: it can be turned on or off by a touch; it is safe as no other heat is safe; it is unaccompanied by smoke or dust; all its appliances are as portable as a hand-lamp; and an automatic regulator may control its temperature and adjust it either to simmering a bowl of gruel or baking a joint. Just so soon as electricity can be won from fuels with an approach to full efficiency, mankind will enter upon the ideal, and probably the ultimate, means of heating and cooking.

Flame Supplanted.

Burdened though it is by the heavy tolls of the steam-engine, electricity has plainly entered the lists of art as a multiplier of all the gifts of flame. Heat, when it springs from an electric source, has a range of applicability denied to fire. It goes where fire is refused admittance and there does its work with unparalleled efficiency. Electric heat creates new temperatures, has a nicety and certainty of touch all its own; joining hands with the decomposing power of the furnace, it redoubles all the triumphs of that old invention. Because electric heat is in so many ways preferable to flame, it has supplanted it in many important fields, and would supersede it in every other were it producible with economy. Let electricity spring from fuels with but inconsiderable loss and we shall see them used for little else than to create electric currents, so much preferable in their heating effects to fire.

Until this generation flame alone was the source not only of heat, but of the beam of candle, lamp, and gas-jet. We are thus led to consider electricity as a light-bringer, in which rôle it once again plays the part of a supplanter.

CHAPTER X

ELECTRIC LIGHT

IN the sparks which were among the first observed effects of electricity lay much promise, for all that they were too faint and fleeting to be seriously considered as sources of light. As soon as frictional machines made way for the voltaic battery there was hope that the new means of producing a current might yield a beam constant and bright enough to be worth having. A metallic circuit had only to be broken and rejoined to emit a succession of brilliant sparks, such as we see sent forth to-day from the trolley-wheel as it jolts away from its wire. But, as in so many other high services, carbon was to prove itself in possession of qualities denied to any other element.

New Lamps for Old.

In 1810, Humphry Davy, at the Royal Institution in London, made two pieces of carbon the terminals of a battery of two thousand cells; he withdrew these carbons by three inches of space, to find the gap between them spanned by a brilliant arc of light—the parent beam of every arc-lamp that has since shone forth. In common with other offspring of electricity, this sunlike ray was very costly in the early days when zinc was its fuel, so that it was little known beyond the walls of a laboratory or a lecture-room. With the cheap current due to the dynamo the arc-light at once sprang into popularity, as its automatic regulation was slowly perfected by a succession of inventors, while its carbon rods were brought at last to a high standard of purity and trustworthiness. Among the men who have simplified the mechanism of arc-lighting, the chief is Mr. Charles F. Brush of Cleveland.

In its conversion of energy into light the arc-lamp is the most effective of all devices, rising as it does to an efficiency of 13 per cent., as compared with 5 per cent. on the part of the incandescent bulb. Petroleum, in a lamp of the best design, has a luminous efficiency of but 2 per cent., a sperm candle 1½ per cent., a gas-flame burning 5½ cubic feet an hour, with a Welsbach mantle, 2$\frac{8}{10}$ per cent. The light from illuminating gas may be doubled if, instead of burning it in ordinary jets, the gas is employed to drive a gas-engine, an electric current derived therefrom being sent into incandescent lamps. In the house of the American Society of Civil Engineers, New York, five hundred incandescent lamps are maintained from a gas-engine at a cost for fuel and attendance about one-half that of a street current. In such an installation the electrician exhibits the audacity of a supplanter, employing an electric spark to ignite the successive charges in the cylinder of gas and air of his engine.

The arc-light, for all that its economy is more than double that of the incandescent bulb, has serious disadvantages. It cannot be produced on a small scale, and is therefore too brilliant for ordinary rooms; and as its rays are sent forth from a single point, they form shadows of sharp and unpleasant definition. An opal globe, in reducing the glare of an arc-lamp, absorbs as much as 45 to 65 per cent. of the rays, a large subtraction from the value of the device. In considering these objections it was remembered that the electric current had long been bringing the short metal wires of the miner's fuse to glowing radiance:

why not copy that contrivance so as to obtain a moderate light from a continuous conductor, free from the necessity for any regulating mechanism? The question was easy to ask, but before it was rightly answered there was much to learn.

The Incandescent Lamp.

A blazing pine-knot or the glowing embers of a hearth have, in their time, enabled a good many men and women to continue their tasks of the day, to read their books, to write their letters, to knit and sew. Primitive though such illumination may be, it has something in common with the beam of the incandescent lamp. Let the coals of a grate be shining a dull red, send a quick draught of air upon them from a pair of bellows, and forthwith they glow vividly. A comparatively small elevation of temperature is accompanied by a remarkable increase of light. This was borne out in a discouraging way in the early experiments with metals intended to yield light when white-hot. Before iron, platinum, or iridium could be brought to a satisfactory radiance, the intensity of electric heat had softened or even melted the wire.

In 1841 it occurred to Frederick de Moleyn, an Englishman, that improvement lay in inclosing the metallic wire in a glass bulb from which nearly all the air had been exhausted. His device had merit, but did not overcome the whole difficulty. Two of its advantages were clear: it preserved his wire from oxidation, and when platinum was employed there could be no troublesome absorption by its surface of atmospheric gases. The main fault lay in the use of any metal at all as the substance to be set aglow; and yet, because his vacuous bulb is essential to the incandescent lamp of to-day, De Moleyn deserves to be remembered as among the men who have made that lamp possible.

An American inventor, J. W. Starr, saw what was the matter with De Moleyn's contrivance. He knew that carbon was giving a superb light in the arc-lamp, and he felt certain that the same element could be substituted with profit for metallic wires. In association with King, an Englishman, he produced a lamp which in essence is the lamp of to-day, employing a slender rod of carbon, *A*, clamped at its ends to metallic conductors, *C* and *D*, and placed in a vacuum above the mercury in a barometer tube (Fig. 42).

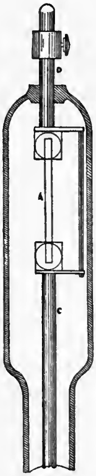

Fig. 42. First incandescent lamp.

This rod of the Starr-King lamp was slender, but not slender enough. When the dynamo cheapened electricity so much as to revive interest in the invention, it became clear that it was not a rod that was needed, but a mere thread or fibre. For the discovery and treatment of suitable forms of carbon, and for the mechanical refinements requisite for complete success in their use, the principal credit is due to Thomas Alva Edison. The quest for proper filaments occupied him for years and demanded the most generous outlay. Every characteristic North American fibre was tested in vain, and explorers were despatched to Brazil, to Africa, to gather other fibres in the widest variety. At the end of many thousand experiments, finely divided and shaped strips of bamboo gave gratifying results.

Further success came to him, to J. W. Swan of Newcastle-on-Tyne, and to other inventors, when art as well as nature was laid under contribution. Paper and threads of cotton and silk were charred with scrupulous care, while carbon of the finest grain reduced to powder was moulded into delicate threads under severe pressure. The chemists were next enlisted; for what is chemistry but the mechanics of the atom instead of the mass? Pure cellulose was dissolved in zinc chloride, and forced through narrow dies into alcohol, which transformed it to a solid thread.

Celluloid was suitably bathed, modified, and shaped into filaments for a carbonising process. These and similar methods, some of them trade secrets, are to-day producing lamp-threads of high merit, each adapted to its particular line of duty, and superseding bamboo.

At first no filament lasted for more than fifty hours of service, making the cost of renewing lamps as great as the expense of current. In casting about for the cause of this lamentable mortality it was noticed that the filaments glowed more brightly at some points than at others, indicating a variation in their thickness. Could a remedy be found by making them of uniform diameter? Fortunately, yes. Several years before that time, M. Duprez, a French chemist, had recorded one of those observations so common in science, which at first seem merely curious, but which afterward point a way out of some pressing difficulty. He remarked that in an atmosphere of hydrocarbon a heated stick of carbon received upon its surface a deposit of an extremely dense form of the same element. Sawyer and Mann here found a capital means of lengthening the life of the filament. Immersing it while luminous in a heavy hydrocarbon gas or liquid, it took on a solid coating, and where the filament was thinnest, and therefore hottest, the deposit became thickest. In this ingenious way the thread was bidden to repair its own defects, and took a bound toward virtual perfection. The squirted filaments of to-day receive in a similar manner a dense coating of graphitic carbon, at once more durable and more light-giving than its basis of amorphous carbon.

To a further refinement of ingenuity the incandescent lamp owes another feature of its excellence. To be efficient it is needful that the air be excluded as thoroughly as possible from its bulb. Any oxygen that remains will combine at once with the carbon of the thread to shorten its life. Notwithstanding his use of the best pumps, Mr. Swan detected that his filaments were attacked by oxygen, and in a quantity greater than could possibly remain in a bulb after the well-nigh complete exhaustion of its air. It occurred to him that perchance a little oxygen had been left in the substance of the filament itself, for he well knew how strong is the affinity between gases and the porous forms of carbon. It is this occluding or hiding power which gives charcoal its usefulness in preserving foods by absorption of deleterious gases. Thought he, It may be that if the filament were kept aglow during the pumping operation, its oxygen would be dislodged and removed with the free air of the bulb. Experiment proved the soundness of his surmise, and lamp-making was advanced by another important step. To-day a chemical absorption of the air from a lamp occupies one minute; at first for this task a pump required five hours.

In passing the wires bearing a current through the glass of a lamp, a perplexing difficulty arose. As those wires were warmed and cooled when a current was established or cut off, they tended to tear themselves away from the glass in which they were embedded. This was overcome on discovering that platinum when heated has much the same rate of expansibility as glass. Who shall say that the ascertaining any property of matter whatever is mere idle curiosity? When a particular substance is wanted, a work of reference, such as Clarke's *Constants of Nature*, is an inventory which may tell us exactly where to find what we need. The tiny bit of platinum has been indispensable to the incandescent lamp, and the demands of the electrician, as in the case of copper, have had a decided effect on the price of the metal. Because the glass which the platinum enters is very strong it may be thin, so that a very short wire of the costly metal suffices. Recent experiments with an alloy of nickel and steel show it to have much the same rate of expansion and contraction as glass when exposed to heat and cold; this alloy, therefore, may prove to be available as a conductor for incandescent lamps instead of platinum.

In augmenting the light to be had from a given current, two paths are open to the inventor. He may either intensify the current, and be rewarded as if he were to work the bellows on his hearth that he may read by the light of its flame, or he may choose a substance which shines with peculiar brilliancy when brought to a very high temperature. This twofold quest is surrounded with difficulties. In lamps of the latest type the filament is stout enough to bear a current of from 200 to 250 volts, with a life usually one-third longer than that of lamps adapted to a current of 110 volts. But there is a limit to the heat which even the most refractory substances will bear, and of this we have an illustration not infrequently. Sometimes an accident at headquarters sends a current of double voltage through the filament of a lamp; for a few seconds the thread glows with eightfold its former intensity, and we are tempted to think that here is a way of getting vastly more light out of electricity than we have ever had yet. But the thought has scarcely time to pass through the mind before the filament breaks under the strain of a temperature close to its point of fusion. Within the narrow bounds of experiment it has been ascertained that a threefold current exerts a twenty-sevenfold power of illumination—that the exaltation of light is as the cube of increase in the current applied. Plainly, the electrician is here rigidly fenced in by the melting-points of the materials he sets aglow.

But among these materials there may be some which exceed carbon in radiant quality, and it is along this line that inquiry is now directed. One of the best illuminants is the oxyhydrogen flame as it plays upon a block of lime; a light of yet greater brilliancy bursts forth as magnesium burns to form magnesia. Both these facts may have had a hint for Auer von Welsbach when he entered upon the researches in which he has won distinction. In his incandescent mantles for Argand burners a gas-flame is doubled in light-rays through playing upon a film of oxides, chiefly those of thorium and zirconium. In recent experiments he has found that threads of osmium, ruthenium, and thoria yield an excellent light when conveying an electric current. These materials are costly, and their preparation is difficult. Yet, with the cheapening which is likely to follow an enlarged demand, and the knowledge which rewards persistent and concerted attack, it may be that the success of the incandescent mantle with gas is to be repeated with electric lighting. Chemistry here has not said its last word.

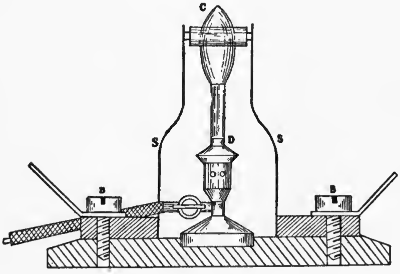

FIG. 43.
Nernst lamp.

On a related line of experiment, Mr. Edison has recently modified the carbon filament of his incandescent lamp so as to adapt it for use on high-tension currents. This new filament is compounded of carbon and of rare earths, such as the oxide of zirconium or of thorium.

The Nernst Lamp.

Following a somewhat similar line of investigation, Professor Walther Nernst of Göttingen has devised a lamp of tested utility. Between two platinum springs he places a cylinder formed of any substance, such as magnesia, which is refractory to heat, and at the same time refulgent at a high temperature. A cylinder of magnesia at common temperatures is a poor conductor, but when heated it carries a current with ease. An auxiliary current, or flame, warms the magnesia at the outset of its work, and, that done, a strong current enters and keeps the cylinder vividly aglow. The

Nernst lamp enjoys all the economy of the arc-lamp, and offers the further advantage that it can be manufactured in smaller dimensions and serve smaller spaces. How far the necessity for beginning by warming its cylinder may work to its disfavour is a question which only experience can decide (Fig. 43). *BB* are binding-posts through which a current is sent to the two metallic springs *SS*, which hold the light-giving body *C*. The flame of a lamp, *D*, brought under *C* for a few seconds, warms it to the point of conductivity.

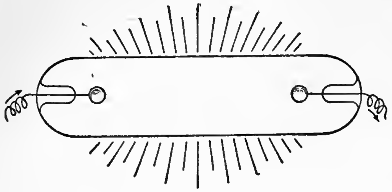

FIG. 44.
Simple Geissler tube.

Tesla's Experiments.

Many attempts have been directed to producing electric light by means other than the arc of two carbon pencils, the filament or the rod aglow. Tesla, in experiments of great interest, has returned to the original phase of illumination as due to pulses of extreme intensity. We can follow his successive steps if we begin with a common Geissler tube, almost exhausted of air, its electrodes, or current carriers, extended just within the glass (Fig. 44). On sending an alternating current of high intensity through the tube from one electrode to the other, the gas commences to gleam, and through a spectroscope its characteristic lines and bands come clearly into view. In a second and similar tube the electrodes may remain outside the glass, but in contact with it, while the luminous effect continues unabated (Fig. 45). The electrodes may be re-

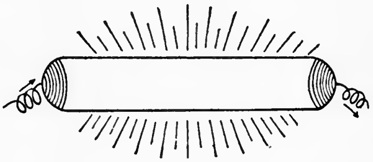

FIG. 45.
Geissler tube with external electrodes.

moved farther and farther from the tube, and may finally be soldered to large sheets of metal forming walls as much as fifteen feet apart; with pulses of redoubled tension anywhere within these walls, the tubes or globes, exhausted as before, may be waved about while they continue to shine vividly. No electrical experiment is more astonishing than this, accustomed as we are to supposing that for a luminous effect a metallic tie is imperative (Fig. 46).

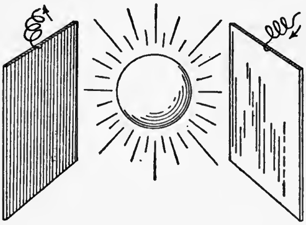

FIG. 46.
Glass sphere luminous between two metal plates.

In large exhausted tubes Mr. D. Macfarlan Moore converts night to day with a brilliant and continuous band of light similar in origin. Franklin identified the spark of the Leyden jar with the lightning of the sky; Geissler, Tesla, and Moore have shown that the aurora borealis and the rays from a rapid alternating machine are one and the same. As yet the aurora of mechanical birth is too costly to take a place in the market beside the arc and incandescent lamps. In demonstrating that a gas, without rising in temperature, may be lashed by electricity to all the glow of flame, the artificial aurora sheds a ray of explanation on the aurora of nature, and points the way to that desideratum of electric art—light without the present enormous waste attending its production.

To the eyes of early observers light was always associated with heat, and the auroras of the upper air, as well as the nebulæ of the remotest heavens, were deemed to be hot like the stars, simply because they shone with brightness in the sky. Recent and critical examination discloses that both auroras and nebulæ are probably intensely cold—a degree or two, perhaps, above absolute zero. Within the past decade attention has been turned to living examples on earth of light generated without heat as a companion. The glow-worm, low as it is in the scale of life, accomplishes the feat. So in more striking fashion does the firefly, especially in the large species *Pyrophorus noctilucus*, which flourishes in Cuba (Fig. 47).[1] In music, as Lord Rayleigh points out, we may strike the higher octaves at once, and strike them only, but in reaching the upper octaves of the molecular music we call light, we must bear the company of the lower scale of heat, however costly, useless, and offensive it may be. The electrical engineer has only to read the secret of the glow-worm and the firefly, as they shine in his path, to find his goal in the full conversion of the energy of his fuel into light.

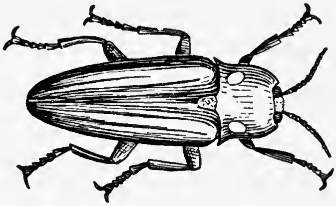

FIG. 47.
Cuban firefly (*Pyrophorus noctilucus*).

The Gifts of Electric Lighting.

Energy in the heat of a steam-boiler as applied to producing electric light rarely rises to an efficacy of as much as one-hundredth part; and yet, for all their waste, electric lamps mark the longest stride ever taken in the art of illumination. The beams of the arc-light abound in the full variety of rays to which the sun has accustomed the eye, while the proportion of light to heat is much greater than in any other artificial illuminant. In its "inclosed" types, usually of moderate dimensions, the arc-lamp yields rays resembling those of daylight in their diffusion, while the inclosing globe abolishes all peril from detached particles of flaming carbon, or the accidental touching of the carbon rods by inflammable materials. Other advantages are enjoyed. An ordinary arc-lamp is

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[1] An elaborate study of the light of this insect appears in a paper, "On the Cheapest Form of Light," by S. P. Langley and F. W. Very, *American Journal of Science*, Vol. XL, August, 1890.

operated by a current of 45 volts; an inclosed lamp of the "Helios" pattern employs a current of 80 volts, so that its carbons are farther apart, with a broader path for the emission of light. The pencils occupy a small glass cylinder closed at the base; the air in this cylinder becomes intensely hot, and is correspondingly attenuated, with the effect that its oxygen attacks the carbons much less than the oxygen of the open air attacks the pencils of a common arc-lamp. The regulation of a "Helios" exhibits a return from complexity to simplicity: two electromagnets are directly energised by the lighting current; at its full strength that current by means of a lever draws the carbons apart; when the current grows weak the lever relaxes its grasp and permits the carbons to approach.

When manufactured in its boldest proportions, the intensity of the arc-lamp has created for it a new field. Mounted upon a tower on land or at sea, it is a search-light of golden value in both peace and war, disclosing in the one case a path of safety to the mariner, in the other making as clear as sunshine the best line for attack. By using it for throwing signals upon the clouds, according to a code, during the South African campaign in 1899 messages were read between Kimberley and Phillipstown, a distance of 115 miles. The Suez Canal is navigable by night as easily as by day, thanks to the arc-lamps of its steamers. In a very different field, an electric search-light has just been impressed into the service of the fire department of New York, making clear the best points for work by the corps.

The incandescent lamp, by comparison feeble, is nevertheless, in the sum total of its uses, more important than the arc-light. Shut up inside its empty bulb, it neither consumes nor pollutes the air. As comparatively little heat attends it, and because it is strictly secluded from the atmosphere, it is safe where any other light would be hazardous, as in gunpowder-magazines, in collieries liable to fire-damp, and in flour-mills where a fine explosive dust rises from the machinery. Its use banishes the match, from which so large a number of "accidental" fires arise.[1]

It goes where no other light can go: under water as an aid to the fisherman and the diver; beneath a balloon, or within it, as a signaller a thousand feet or more above the ground; while the surgeon introduces it into the throat or stomach of a patient to explore the tract of disease. Armed with an automatic appliance easily actuated by electricity, a light may be left to itself in full confidence that it will be maintained, for on the instant of accidental extinction a neighbouring lamp is set aglow.

Now that houses, concert-halls, and theatres are lighted by electricity, their air is much less impure than when gas was employed, and because less ventilation is necessary than of old, there is a lessened demand for heating in winter, with a diminished play of baleful draughts. An eminent musical critic of New York declares that to-day we live in the golden age of song. This is without doubt to be credited in part to the electrician, who provides singers, musicians, and conductors with much better air than they ever enjoyed before the era of electric illumination. The same good atmosphere bestows upon the contents of libraries, picture-galleries, and museums a lengthened lease of life. In the mansion electric lighting confers upon decorative art a new and delightful resource; in the theatre it gives the stage-manager instant and easy control of hundreds of lamps scattered in front of and behind his drop-curtain; it grants him a simulation of dawn,

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[1] During the year 1898 the total number of fires in Boston was 1980.

Caused by matches and rats	30
Caused by matches and children	78
Caused by careless use of matches	107
	215

of moonlight, and of storm unknown before the electric age.

Electricity has thus entered the domain of light as a multiplier not less potent than in the field of heat. It reduces the waste attending the production of light from fuels, grievous though that waste continues to be. It brings illumination to a new intensity, and therefore to a new field. It promotes cleanliness, safety, and health. As it can be divided into small units with the utmost ease, it affords the engineer a new facility in distribution. The first arc-lamps, powerful as they were, needed an elaborate system of lenses and reflectors to give their rays a useful diffusion. With incandescent bulbs arrived a better method. Their wire may turn a corner every foot for miles, and, none the worse, yield a sufficient beam at every rod of the journey. To borrow a phrase from the mathematicians, electricity raises all the old arts of lighting to a new power, and creates, as we shall presently note, a beam with powers denied even to the solar ray.

CHAPTER XI

ELECTRIC BATTERIES

The Primary Battery and the Electroplater.

IN the fields of electric heat and light we have seen how electricity began by doing an old task in a better way than fire ever did it, and then passed to the performance of work quite beyond the scope of fire, however well directed. The history of the voltaic battery repeats all this. In its original form this device was offensive and irregular in its action, short-lived and dear. Its best modern types emit no odours, give an equable current, cost but little when at work and nothing at all when idle. For many purposes, where a small current is enough, and its use infrequent, as in ringing a door-bell or touching off a fuse, the voltaic battery is not likely to lose its place. But it is rather in its offspring than in itself that this primary battery has claims to distinction.

This was indicated early in its history. It was noticed by the first experimenters that its processes of wasting away could be readily reversed, that if a current from one cell were led into another, it was easy in the second cell to obtain a deposit of solid metal from its solution. Thus electroplating was discovered, and tasks long accomplished only by fire were handed over to electricity. Before 1840, silver plate was made by soldering a thin plate of silver to a sheet of copper, which was then rolled out and shaped into cups, bowls, and pitchers. A similar method of manufacture survives in the Crooke process, by which lead-foil is surfaced with tin as a damp-proof lining for packages and an impervious covering for corks and stoppers.

The results achieved by the electroplater are much more refined and delicate than those possible to fire. Heat causes an expansion in metals which seriously interferes with nicety of execution, which often demands in a coating of gold or silver much more metal than when the film is deposited from an electrolytic solution. The contrast between old methods and new is very striking in the manufacture of "galvanised" iron. The original plan was to dip iron into molten zinc. This process is now being replaced by immersion in a cool, electrolytic cell in which the zinc is deposited in a closely adherent film, smooth in surface and exactly uniform in thickness; the zinc, united to the iron in the molten bath, has not the same excellence.

To prepare solutions which give the electroplater the best results with his various metals has been a prolonged and difficult undertaking. To deposit a film of silver successfully the metal must be of close coherent texture; only at the end of many and costly failures was it ascertained that silver of durable grain is to be had only from its solution in cyanide of potassium. The deposition of nickel was for years a baffling problem until Isaac Adams of Boston found that nickel salts were usually contaminated by nitrate of soda; when this intruder was ousted there was little further difficulty, and to-day stoves, cutlery, and hardware of great variety are given a tough and handsome coating in the nickel bath. With modified solutions of copper, zinc, nickel, and silver, adherent coverings of these metals have been given to wood, vulcanised fibre, and hard rubber. The wooden handles of tools and instruments exposed by turns to wetness and dryness may thus be rendered durable with no sacrifice of lightness. Ornamental carvings and mouldings are in like manner given a strong and beautiful shield of metal. On occasion the bath may be of huge proportions, as in one of the boldest tasks ever essayed by the electroplater—in adding a surface of aluminium to the metal which afterward rose as the dome of the City Hall in Philadelphia. The total area treated was 120,000 square feet, and included masses weighing 10,000 pounds.

The ship-builder is not negligent of the value of electroplating. The steam-tug *Assistance*, of the United States navy, is a vessel whose iron plates were electroplated with copper early in 1895. During four years of constant service her plates remained free from barnacles or marine growths of any kind. In cost this process is considerably less than that of ordinary copper sheathing.

A Rival of the Foundry.

One of the prime uses of fire to the savage was in the casting of metals. It was an immense saving of time and strength when, instead of having to beat a mass of copper into the shape of a club or a hammer, he found out how to fuse the metal in a blaze, pour it into a mould, and let it cool. All that the savage ever accomplished in thus making fuel do his work was vastly extended and lifted as the arts of the metal-worker rose to more and more of skill and deftness. Early in the development of the voltaic cell these ancient arts of the founder were obliged to face rivalry from an unexpected quarter, for the electrician soon passed from the enrichment or protection of surfaces to the duplication of an entire object. At first, of course, small things were the means of showing what the new agent could do. For example, a medal would be copied by taking a mould of it in wax or plaster of Paris and dusting this carefully with a conducting film of plumbago; on immersion in a suitable bath, after attaching the mould to the positive pole of a battery, the original was accurately reproduced. Here for the first time was deliverance from some of the evils attending the use of fire for such a task. Because there was no expansion due to heat the reproduction was exact in its every line, there was no burning with its liabilities of injury and discoloration, and the operator did his work without inconvenience from the glare of flame or the temperature necessary to fusion.

It was not long before the electrical mode of duplication was extended to pages of printers' type, for which moulds of gutta-percha are found to be best. In like manner etched and engraved plates are faithfully multiplied. The gain in all this is that the originals are copied with the utmost precision, while they are preserved in their first perfection free from the touch of ink and the abrasion of the press. Electrotypes cheaply made are renewed as soon as they show signs of wear, and the modern printer's high standard of execution thus owes not a little to the electrician's aid. Thanks to electrotypy, not only ordinary illustrated works, but atlases and maps, are now issued in large editions at a fraction of their former cost. The engraved maps of the Ordnance Survey of Great Britain are never directly used in the press; at stated intervals in their constant revision they are handed to the electroplater to be copied and published at low prices.

To-day with the cheap current from the dynamo the electrician rises to bolder flights than these. No longer does he treat mere surfaces for the silversmith, or thin plates for the printer, but takes in hand the clay model of the sculptor, large and irregular in its mass, for exquisite duplication. In materials impervious to liquids, and highly elastic, he forms a mould of a bust or a group; when a metallic deposit is secured, the mould is easily removed. Or, he may repeat one of the steps of the casting process, and make his mould in several parts. The statue of San Fidele, at Palazzolo sull' Oglio, Italy, was thus produced in seventeen sections. It stands 23 feet in height as it surmounts the Torre del Popolo; as its plates are but one-fifth of an inch thick, its weight is but 1760 pounds. Another striking example of the same feat is the Gutenberg monument at Frankfort-on-the-Main, whose three life-sized figures, created by R. Schmidt von der Launitz, sprang not from foundry flasks, but from the electric bath (Fig. 48). Let the current become still cheaper than it is to-day, and the founder may see the whole of his business transferred to this formidable rival, the warping heats of sand-moulds banished, the scorching temperatures of crucible and ladle a reminiscence. Again we see flame outsped, its feats surpassed.

FIG. 48.
Gutenberg statue,
Frankfort-on-the-Main.

Smelting Finds a Competitor and the Miner Saves Much.

The ability to effect chemical separation without heat lifts the latch to a numerous array of industrial processes. It brings to that venerable contrivance, the smelting-furnace, a new and unforeseen competitor. In the important field of dissevering metals directly from their ores an auspicious beginning is recorded, while about three-fourths of all the copper now mined is refined electrolytically, furthering the electric arts by handing them conductors of new purity and efficiency. One of the largest works in the world, those of the Boston and Montana Copper Company, at Great Falls, Montana, employs in this service 3000 horse-power, supplied by the Missouri River. The copper ore is first mechanically concentrated, then roasted, next smelted into matte and blown into plates; these are suspended in large tanks, filled with a solution mainly composed of copper sulphate and sulphuric acid. A current of feeble intensity and large amount is passed through the tanks in succession, and the metal is deposited, as in electroplating, on sheets of copper which thicken rapidly and prove to be almost pure. The refuse which falls to the bottom of the tanks yields in silver and gold much more than enough to pay the cost of the whole refining operation.

A new source of profit in mining consists in being able thus to pick up with electric fingers what a few years ago were unconsidered trifles—chiefly because they were beyond the play of flame. To July 1, 1898, the Anaconda Copper Mining Company of Montana had recovered as by-products 40,658,103 ounces of silver and 135,244 ounces of gold. The gold, in a weak solution of potassium cyanide, may be but from 25 to 100 grains in a ton, and yet so efficient a searcher is electricity that from such a liquid more than 46,000 ounces of gold were separated in 1896 in the Transvaal. No furnace method has so extraordinary an efficiency. To-day this electrical process is in much extended use throughout the world, and so are similar modes of recovering extremely small fractions of silver from ores of lead. No wonder, therefore, that ores so poor as to be long neglected, and slimes for years cast aside as waste and worthless, now receive the chemist's careful study.

One of the strange facts in this department of his activity is that one metal may be easily separated in the presence of another; zinc, for example, is deposited almost chemically pure from an ore which also contains lead. This is of a piece with the singular fact that in a plating bath an alloy, such as brass or bronze, can be deposited as an alloy, although with much more difficulty than either copper or tin.

A Divider and Uniter for the Chemist.

A new horizon spread itself before the chemist when Davy, in 1807, employed the electric current to decompose potash and soda, releasing potassium and sodium for the first time from their compounds, and accomplishing the feat without fire. When heat is applied to a solution until the temperature reaches an extreme pitch, the usual effect is to evaporate the liquid without chemical change. Often, too, the application of extreme heat to a solution yields results of an undesirable kind. In supplanting heat by electricity the chemist has a parting agent which does his will at ordinary temperatures, and whose products he can determine through an ample range of choice. Place a little water in a platinum tube, heat the tube intensely, and the water is divided into hydrogen and oxygen gases. These gases are diffused as a single mixture; they combine to form water once more the instant that their heat is permitted to fall below the temperature of dissociation. Observe, in contrast, the separation by electricity of these same gases. Each of them is now borne to a tube or other receiver of its own, all, too, in the absence of any heating effect. This fairly typical case shows us the new scope which the electric current as a divider affords the chemist. From common salt dissolved in water Mr. E. A. Le Sueur derives sodium and chlorine. The chlorine is divided into two portions; one immediately forms caustic soda, the other enters a chamber of lime to produce bleaching-powder. The same products are obtained by a variety of other ingenious processes. A large group of chlorates, including potassium chlorate, which is both a useful ingredient of explosives and an important medical specific, are manufactured by electrolysis; so are chloroform, iodoform, and other resources of the dispensatory.

The electrician sets up a partnership not only with the druggist, but with the sugar-refiner, contributing as his share of the capital a refining method so excellent that four-fifths of the sugar previously left in the waste liquor is now saved. He next assists the tanner, having learned that under electrical stimulus liquids have a new power of penetrating the hides in their pits. With the aid of a current changed every minute in direction, as much work is done in two hours as formerly required from ten days to three weeks.

In the early working of the frictional electrical machine a strong odour was remarked, soon ascertained to be due to the atmospheric production of ozone—oxygen in an intensely active form. Ozone is now turned out on factory principles at the rate of 135 grammes per hour for every horse-power employed. It has widely diversified uses: it oxidises oil for the paint trade; it seasons the floor-cloth known as linoleum; it purifies drinking-water; it is an invaluable bleacher, and in the manufacture of sugar its bleaching quality reinforces the purifying effect of an electric current. In these manifold activities under the hand of the chemist he bids electricity do much that is impossible to flame, however skilful its application. Take the production of ozone, for example: a very moderate degree of heat speedily brings it to the form of oxygen and so destroys its peculiar value.

Electricity has remarkable powers of effecting chemical unions as well as separations, and under circumstances where fire must not appear. Cavendish, late in the eighteenth century, performed a notable feat when he united hydrogen and oxygen by an electric spark to form water. To-day methane, ethylene, acetylene, and ethane are each combined with oxygen by the same simple agency. As the chemist thus beats his electrical sword into a trowel, he builds structures prophetic of the day when the slow elaborations of the farm and field may be imitated by the artificial synthesis of sugars, oils, and starch. A variety of dyes, oils, and acids, nearly two hundred in number, produced in nature as the results of vital activities, are now built up from inorganic matter. In an increasing proportion of cases electricity is the agent which either builds a molecule from simpler substances, or disengages a compound from a structure more complicated than itself. Van 't Hoff, in a memorable address delivered in 1898, stated that we stand very near the time when the chemist will be able to produce albumen in the laboratory. That his prophecy is reasonable appears from the researches of Schutzenberger, who devoted years to the study of this subtile compound, and who found that three out of the four molecules into which it may be broken up can be created artificially.

The Storage Battery.

When, in Chapter VII, a word was said about carbon, we noted how remarkable a reservoir of energy it is, a single pound of it in burning giving forth as much heat as would be produced from a horse-power applied for five hours and forty-two minutes in tasks of friction or percussion. And yet, as reservoirs of energy, fuels of all kinds have their disadvantages: they only yield their motive power when burned; to get up steam in a boiler takes time and so makes difficult the application of the steam-engine for many minor and intermittent demands; even a gas-engine asks a few minutes before its wheels can go round after a period of rest and coolness. Metals, for all their excess in weight beyond common fuels when energy values are considered, offer themselves as reservoirs of motive power preferable in many ways to heat-engines, however well served by fire-wood, coal, or oil. The indication here lay in remarking that a metal as it dissolves in a common acid solution generates heat, while the same metal dissolving in a voltaic cell gives forth, not heat, but electricity, and this instantly at a touch, while, when the cell is not at work, its acid exerts no corrosive action.

In the broad field of the electrician, two distinct types of apparatus have for many years been familiar: first, a voltaic battery in which metal dissolves and yields a current; second, a plating battery in which a current deposits metal from its solution. In the details of their action these two kinds of apparatus differ radically. For a long time inventors tried to devise a storage battery which by turns would yield a current as its metal dissolves, and anon take in a current to build a mass of metal from its solution. The problem thus put seems easy, but it has presented obstacles so stubborn that only recently have they been overcome.

The core of the difficulty lies in the fact that dissolving a metal in an acid bath is not so simple as it looks, and that therefore to reverse the process is an arduous task. In the architecture of the molecule, as in that of a house, there may be doors of two different sorts. One of them swings either forward or backward; it may be pushed or pulled open; it acts reversibly. Doors of this kind swing apart as the chemist decomposes water; they close behind him again as hydrogen and oxygen fly together as water once more. Another type of door, much more common, is hung like a valve so as to move only in one direction: it admits easily enough, but permits no return. Push it from the wrong side, and it is shut all the tighter, standing typical of an irreversible process in chemistry. To use a homely illustration of an irreversible chemical change, let us fry an egg over a gas-jet; no cold, however intense, can unfry it, and no electric current, however strong, can restore it to its first estate.

From a change as intricate as that of a cooked egg let us pass to one as simple as the decomposition of water—we shall find it less simple than it appears at first view. When we apply the poles of a battery to initiate the separation, a little sulphuric acid must be present. Many electricians of mark are disposed to think that, from first to last, it is nothing but sulphuric acid, re-formed from moment to moment, that is affected by the parting. It is worth remembering at this point that the action of a voltaic cell is much the better for rubbing its zinc plates with mercury. Just why this should be, nobody knows. For a successful storage battery, one that works either way with ease and economy, no metal pure and simple gives satisfactory results. The electrician employs lead in its compounds; these are further compounded as they unite with elements presented in solutions of sulphuric acid. Compounds of lead are preferred to those of any other metal because they are insoluble in an electrolytic bath.[1]

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[1] E. J. Wade, in an article in the *Electrician*, London, Vol. XXXIII, p. 603, says: " Herein lies the superiority of a lead-lead-peroxide cell to all others. If properly treated, it may be regenerated electrolytically, and so nearly to its original chemical and physical condition that it can be charged and recharged in this way hundreds and even thousands of times before the total results of the slight changes that do take place depreciate it sufficiently to incapacitate it for further use, while with all other cells the changes that occur with each charging are relatively so large that although all possible means have been tried to reduce them to the minimum, they rapidly deteriorate, and require constant attention and repairs. The reason for the complete reversibility of the lead cell is entirely due to the chemical behaviour of certain of the compounds into which the metal enters. Lead alone, of all the metals, forms a sulphate that is practically insoluble and unacted upon by water and dilute sulphuric acid, and it also combines with oxygen to form a peroxide, having a good electrical conductivity, and equally unaffected by the liquid. When, therefore, a lead-lead-peroxide couple is discharged in dilute sulphuric acid, the lead sulphate, which is the ultimate product formed at the poles, does not dissolve in the solution, but remains on the surface of the plates, ready for reduction and reoxidation when the current is reversed. Any local action that goes on when the cell is not at work also results in this insoluble sulphate, which tends to form a protective coating on the metal, and thus reduces losses from this cause to a minimum. The compounds formed, when other metal than lead is used as the negative, not necessarily in a sulphuric-acid electrolyte, but in any other practically possible solution, are all soluble, and dissolve in the liquid as fast as they are formed, and this simple fact has, up to the present, barred the way to any substantial progress with these classes of reversible cells."

As a storage cell is charged and discharged it offers baffling problems of chemical reduction and combination. Experiment here has outdistanced analysis, and even the best apparatus leaves much to be desired. The formation of lead sulphate yields little energy in comparison with the combinations into which zinc, iron, or copper freely enter. The active lead material needs a grid or support of inactive structure, which may be several times its own weight. And further, the formation of sulphate screens the inner portion of a plate from effective work. Thus the really useful part of an electrode may be no more than from 5 to 15 per cent. of its total weight.[1]

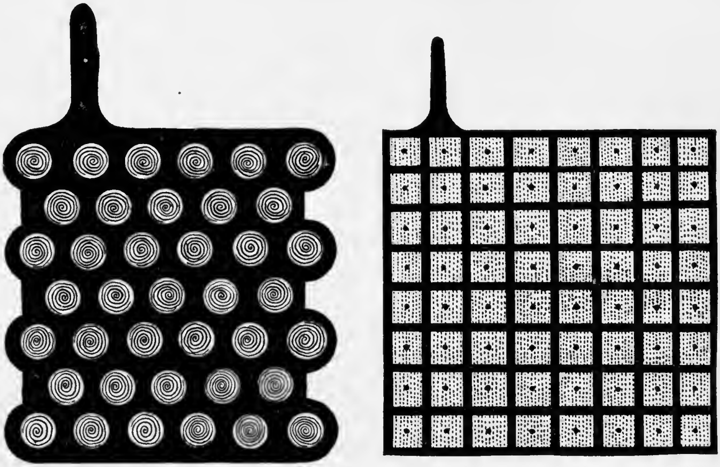

FIG. 49.

Positive and negative plates, Electric Storage Battery Co., Philadelphia.

The batteries of the Electric Storage Battery Company of Philadelphia have won wide favour; they derive an advantage from a detail of form. The lead for the positive plate is curled up into small spirals resembling shavings as they leave a carpenter's plane. At the outset of operations

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[1] London *Electrician*, Vol. XXXIII, p. 605.

they are fastened into sockets where they rest securely; as they grow bigger in chemical combination there is ample room for them (Fig. 49). In earlier batteries there was a good deal of trouble as the lead left its net or grid in the successive alterations of its bulk. It is claimed that the positive plates in this battery survive alternate charging and discharging for 40,000 hours before they are destroyed, and that the life of the negative plates is thrice as long.[1]

A Reservoir and an Equaliser.

For the empire of electricity an effective storage battery means the dawn of a new day. A dynamo sends it currents derived from wind- or water-powers, or from engines temporarily laden below their capacity, and these currents effect chemical restorations somewhat similar to those of electroplating. Then, at need, the storage battery yields electricity much as a voltaic battery does. Let us make no mistake as to what is accumulated in a storage battery; it is not electricity, but a metal, or a metallic compound which generates electricity on request. When a householder fills his coal-bin he is not storing fire, but a fuel which will give him fire whenever he wishes.

In the propulsion of launches and yachts, carriages and wagons, the storage battery has a field that grows wider every day. A ton of coal can be carried from Scranton to New York, 150 miles, for less than the cost of haulage one mile through the streets of the city. Not only is horse-power more expensive than that of steam in a huge locomotive, but a Mogul engine, as it takes 1000 tons of coal to market, is in charge of but two men; it requires the same number of men to deliver a single wagon-load of coal to a customer in New York. Moreover, as cities grow in size,

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[1] *The Storage Battery*, by Augustus Treadwell, Jr., New York, Macmillan Company, 1898, is a capital treatise describing storage batteries of various types in detail.

the average dwelling, store, or factory recedes farther and farther from the railroad station, or the steamboat landing, with a steadily increasing tax for haulage.

Hence the clear promise of success as the electrical engineer begins to displace the city horse with the electromobile wagon and cab. In this field his battery is distinctly superior to oil or compressed-air motors. It is safe, as it contains nothing inflammable or liable to explode; it is easily handled and controlled; it does not offend by heat, vibration, or odour. An electromobile cab in New York has usually 44 cells, each of 9 plates, the whole weighing 900 pounds, and equal to exerting the tractive force of three horses for four to five hours. Such cabs take up much less space than their predecessors in a crowded thoroughfare, while the pavements are rescued from filth, dust, and noise. Freight-wagons have a heavier battery, proportioned to the load to be carried and the distance to be run. It is found that wooden wheels and solid rubber tires form the best equipment for both cabs and wagons. As electric vehicles are multiplied they are likely to put a new premium on good roads, as the bicycle has done; indeed, the outcome of the situation may be to make smooth and easy for the horse the path upon which his rivals have so boldly entered—rivals much less tolerant than he of quagmires and mud.

The storage battery has other uses in transportation. While a ferry-boat lies at its dock, if its engine is busy storing electric fuel, the power there accumulated helps to propel the boat on its next trip. If half the working-day is spent at docks, the engine need be but half as powerful as when unassisted by the battery. On board a railroad train a dynamo rotated by the axle of a car may yield a current for a hundred lamps; before the train comes to full speed, and while it pauses here and there, a small storage battery serves as the source of illumination. It is, however, in acting like a gigantic fly-wheel that the storage battery has its chief importance. To begin with a minor case: In large office buildings and departmental stores the elevator service requires a great deal of power, with sharp alternations of much and little demand. At one moment eight elevators may be in transit, the next moment but two are busy, and so on. At every period, however short, of uncommon activity, the storage battery comes in to aid the dynamo current, which by itself would be inadequate. Whenever the dynamo current is underworked its surplus energy goes into the battery to restore its lead.

Now for fluctuations on a scale nothing short of stupendous: At power-stations in cities the variations of demand are both abrupt and wide. On traction lines there are "rush" hours at the beginning and close of the working-day, when the traffic is doubled or trebled; in lighting plants there is a sharp call for current about sunset. Engines and generators had formerly to be powerful enough to meet the uttermost strain that might thus be put upon them, although but for three or four hours of the twenty-four. With the storage battery to supplement the engines these may be much smaller, because worked uniformly at their most economical pace, which is usually their maximum capacity or a little less. During hours of comparatively scant business the power is turned in part into the storage battery, whence it is released at the call of the heaviest travel or lighting—to "take off the peak," as the engineers say. For such service as this batteries of monster proportions, costing $750,000 or more, are now yoked to the transportation and lighting systems of New York, Chicago, and other great cities.

In the case of water-powers, which run day and night, there is similar profit whether they are used for traction and lighting, or in manufacturing. A mill usually requires power for but ten hours out of the twenty-four; for the rest of the time the electric energy may be diverted to a storage battery so as to cut down the outlay for plant by nearly one-half. As the electrical engineer looks about him for business during the dull hours of the working-day, he espies with satisfaction the constantly increasing number of batteries to be restored for use in cabs, wagons, launches, and yachts. He endeavours also to solve problems in taxation, much as if he were a statesman desirous to stimulate a national industry. He lowers his tariff for the hours of slack demand; he does the same when electricity is used for heating purposes; and he gives a discount proportioned to the amount of current a customer buys. In all this his reliance is largely upon a huge storage plant which may have an efficiency of as much as 84 per cent. At first the dynamo threatened to oust the battery of Volta from all but petty uses, but lo! its cells are now taken from the shelf, made reversible, and promoted to a full partnership. In all this remarkable development fire and electricity join hands for work and for economy, which neither can accomplish alone. In the storage battery the steam-engine finds its complement; when both are in harness for a common task they do their work with an efficiency unexampled in engineering art.

In the world of finance a significant union of traction, lighting, and power-transmission systems is afoot. This movement finds profit in substituting a large scale of operations for a small one; it finds an opportunity, also, to make a slack demand for one service coincide with a lively demand for another. The " rush " hours of the early morning on transportation lines are a time of scant electric lighting, so that then the combination of a trolley with a lighting system is a distinct advantage. Between five and seven o'clock at night, especially in winter, the case is different, for now the requirements for both lighting and traffic are at their height. Here enters the equalisation of pressure by a gigantic storage battery, proving itself the most lucrative feature of the new installations. All this is not without precedent. In the water-supply of a great city a group of engines is kept busy day and night pumping an unvarying stream. Because the water flows into one reservoir instead of into several there follows an economy of power, and a trustworthiness of supply, which the electrical engineer has done no more than copy.

The Chief of the Corner.

Thus in the field of chemical solution, long so humble and subordinate, has electricity proved itself a multiplier of human resources quite as fertile as in provinces of higher dignity, of earlier exploitation. It gives metals a new plasticity without hammer-stroke or flame, and duplicates an intaglio or an etching with a delicacy denied to either tool or fire. It reproduces a statue as easily as a button, while it enables an artist by a flameless method to duplicate his fragile model of wax or clay in enduring bronze. Following all metals to their beds of ore, it enters into rivalry with the blaze which but yesterday was the one agent of dividing metal from matrix, or refining crude masses of copper and silver to purity. Although for its storehouses of energy it uses metals costly as compared with coal, yet so economically are these employed that the storage battery is not only a convenient magazine of power for vehicles,—where heat is inadmissible or objectionable,—but plays an important part in equalising the vast fluctuations incident to lighting a metropolis and transporting its multitudes. There was somewhat of truth in the old supposition that electricity is a fluid; whatever its real nature may prove to be, this much is certain: a current flows into a reservoir and out again with a fluidity little short of perfection.

The storage battery, for all the worth it has in itself, may develop still more as it points to the construction of molecules more intricate than its own. All that the chemist has ever done in breaking up or building compounds in liquid form is extended and heightened as his solutions feel the throb of electricity. We learn how an old castle or bridge was put together when we see it demolished under the strokes of pick and crowbar. The dismantler saves himself needless toil when he follows the lines of the architect as closely as he can. More than one leader in chemistry applies all this to the enigmas of composition, and regards it as only decomposition in reverse. Let these men but follow up the clues already in their hands, let them unriddle the labyrinth of chemical bonds and ties, and there may succeed the creation at will of new artificial compounds of the first importance. The impulse to art given by Volta from his little town of Como may not fully spend itself till this be done. When heat makes its appearance as either a uniter or a separator it often works disturbances greatly to the prejudice of its success; when electricity is the agent this may not be the case. And thus there opens to the chemist another breadth of victories where electricity may either do better what heat does now, or carry the flag into territory where fire may not enter at all.

CHAPTER XII

ELECTRICITY IN THE SERVICE OF THE MECHANIC AND ENGINEER

TO the mechanic and engineer the principal use of fire is in the production of motive power through a steam- or a gas-engine. In a considerable and increasing measure he derives such motive power directly from watercourses hitherto little drawn upon or totally neglected. At this point, therefore, we enter a field where electricity is not in contrast with fire, but creates economies and produces effects quite distinct from those possible to fire—immensely extending every mechanical resource and facility of pre-electric times. As we proceed we shall plainly see why it is that the engineer and the mechanic prefer electricity to any other form of energy, and in a constantly increasing number and variety of cases begin work by converting all their motive power into electric currents.

Electricity Preferable to Other Modes of Motion.

It was Volta, as a chemist, who, devising his cell, first emancipated the electric current for new and unnumbered uses. His successor to-day is the engineer, who wins his spurs by bringing his generator to practical perfection, by improving his steam- and gas-engines to double their efficiency of thirty years ago, or by designing water-wheels of the utmost economy. If to the engineer and mechanic the electric art owes much, magnificently

As a Means of Transmitting Motion.

has the debt been repaid. Of this an illustration displays itself in every street. An old-fashioned bell-pull has a wire which moves as a whole; an electric bell has a wire which as a whole remains at rest while it transmits a current from its push-button; thus does electricity convey motion without movement of its conductor as a mass. Availing himself of this golden property, the machinist removes from his shop a labyrinth of wheels and belts, and puts in their place a few wires at rest, each in charge of the motor actuating a machine. Manifold gains result. The power needed to drive these wheels and belts is saved, and when but one or two machines of a large number are to be set in motion, the economy rises to a high figure, while the workshop becomes lighter, cleaner, safer, more wholesome in every way. Since electricity is of all phases of energy the easiest to preserve from losses resembling leakage or friction, the current can not only be distributed throughout the largest workshop with convenience and economy, but it can be sent to the shop from an engine or a water-wheel many miles away, as in connecting motors at Buffalo to dynamos at Niagara, twenty-four miles distant.

With the conveyance of electricity for distances vastly exceeding twenty-four miles we have long been familiar in the telegraph. The long-distance transmission of mere signals has been followed by that of gigantic powers as a result of advances along several diverse lines of invention: first and chiefly, through perfecting the dynamo which converts mechanical motion into cheap electricity, and the introduction of the motor, which, little else than the dynamo reversed, economically recovers motion from electricity; second, by taking advantage of the fact that the higher the voltage, or pressure, of a current, the less wire does it ask for its transmission. In this particular a stream of electricity resembles a pencil of light. If parallel luminous rays are intensified by lenses, their path is narrowed as they move through space. A current of 1000 volts requires but one-hundredth as much copper to carry it as a current of 100 volts. The copper required for a given distance in transmission varies inversely as the square of the electrical pressure.

Of course the higher the voltage the greater are the possibilities of mischief, and the more costly the coverings demanded for insulation; yet, allowing for every abatement on this score, electricity has marked advantages over any other mode of conveying power afar. Until within recent years such conveyance was commonly effected, as in some of the traction lines of cities, by a swiftly moving cable of steel. Surely, it was supposed, nothing feasible could be more efficient. But mark the superiority of electrical transmission. The current from Niagara has a pressure of 11,000 volts. Were equal energy sent forward as mechanical motion it would rend apart steel cables eight times as large as the copper conductors employed. And this without considering the vast difference between the moderate resistance offered by the copper, motionless as a mass, and the considerable resistance of steel cables advancing and bending round their pulleys at the rate of ten miles an hour, let us say.

During the summer of 1891 a memorable experiment was carried out in Germany between Lauffen and Frankfort, 112 miles apart. A turbine of 180 horse-power was used to generate a current of 25,000 volts, which was transmitted with a loss of but one-fourth. Although no equal distance has yet been covered by a commercial line, a higher voltage is maintained on the wire which connects Telluride, Colorado, with the Gold King Mine, two and a quarter miles away. By employing glass insulators 5 inches high and 5½ inches broad, a current is conveyed at 40,000 volts. Once, at a time of bad weather, the pressure was raised to 50,000 volts; through a fall of damp snow or rain the wires became plainly visible at night, and the characteristic hissing of high-tension currents could be heard several hundred feet away.

How far electric energy may be borne with profit is a question of local circumstances. Where fuel is scarce and dear, where roads are steep and all but impassable, the line may be lengthened, especially when a waterfall may be laid under tribute with but little outlay. In mining it was usual until recently to transport the ore as raised from the shaft to the crushing-mill, which might be miles away. With electricity the transmission of power takes the place of the freightage of ore; the crushing-mill is brought to the mine and the cost of handling and haulage is reduced to the minimum. In the vast region of the Southwest, of which Arizona stands the centre, huge central stations are being erected to supply light and power in districts where wood and coal are scarce or absent, and where all that fertile soil needs is the irrigation that no other agent but electricity can provide. As one improvement in electrical practice succeeds another, as the scale of operations grows bolder, and the rate of interest on sound investments tends to fall, the distances over which currents are borne approaches that of the Lauffen-Frankfort experiment. At Los Angeles, California, a current is received from the Santa Ana River, above Redlands, eighty-one miles distant, at a pressure of 33,000 volts.

The Transformer.

In long-distance transmission it is most desirable that a current should have the highest practicable voltage, but for safety's sake, and to be available in ordinary lamps and motors, it is necessary that the voltage should be reduced—at times to as little as the hundredth part. The appliance which effects this "stepping down" is the transformer. Its work is much the same as that of the wheels which familiarly reduce the motion of the minute-hand of a clock to the slow rotation of the hour-hand; but instead of the rigid push of a small wheel against a large one, the ethereal influence called induction is impressed into service. Induction in its most familiar phase is illustrated when a magnet and a bit of soft iron approach each other. As the soft iron comes into the field of the magnet, it becomes itself a magnet, and at the distance of $\frac{1}{100}$ of an inch its attractive power is almost as great as when the steel and it are joined together. In the same way, as we have already seen, if we have two parallel wires near each other, and send a current through one of them, a current for an instant will be induced in the other (Fig. 34). And for all that we are now observing the action of ether instead of that of palpable and visible masses, the phenomena of induction have a striking similarity to those of wheels in contact.

If we wish to vary the speed of a motion as it is received by one wheel from another, we apply the circumference of one wheel to the axle of another, as in a clock or a watch. When the medium is electrical instead of mechanical (Fig. 50), a current sent through a thick wire induces in a coil of thin wire a current as much more intense than itself as there are more turns of wire in *A* than in *B*. Contrariwise, *A* induces in *B* an electric throb less energetic than that borne by itself in the same proportion reversed. The first of these two actions has long been displayed in this Ruhmkorff coil, an instrument built up of two closely wound coils, one of fine wire, the other of wire comparatively coarse, the second coil surrounding the first. When a frequently interrupted current is sent through the thick wire it excites in the outer coil pulses so extreme in tension as to create sparks eight inches or more in length. Copying this design, a transformer may be built to "step up," that is, to take in a current at low pressure and convert

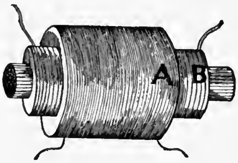

FIG. 50.
Ruhmkorff coil.

it to an intensity which may be a hundred times as great. In "stepping down" the action is reversed: the received current enters the coil of thin wire, and in its neighbour excites pulses of much reduced tension. In its largest and best designs this device has an efficiency of 90 per cent. and more. Its wastes appear in the form of heat, and at Niagara are turned to account in winter for the purpose of warming the house in which the huge transformers are placed.

Motor and Machine United.

In a workshop a current is superior to every other prime mover. A thousand feet of belting one inch wide must pass round a pulley in a minute to transmit a single horse-power. An electric motor without belt or gearing becomes one with the wheel of a sewing-machine, a burnisher, or a pump, and there, as elsewhere, expense ceases the moment the current is switched off (Fig. 51). The adjustment and control of a lathe is particularly simplified by this new mode of actuation. A flexible lamp-cord can bring in its power, and the heavy machine, like many another, is started, stopped, reversed, or varied in speed by a touch upon a regulating handle. The versatility of the electric motor is as well attested in a coal-mine as in a workshop. First of all, a machine undercuts a bituminous seam with twenty times the effect of a pick and shovel; the coal is thrown into a wagon and a second motor hauls it away; from the bottom of the shaft another motor lifts the load to daylight, while a fourth is busy maintaining a current of fresh air.

In an iron-mine, wherever the rock is hard, the best drill is still driven by compressed air, which is an aid to ventilation and coolness, but for every other service electricity is in commission. All the way from the ore-bed to its issue as pig-iron, or steel billets or rails, the metal at almost every turn is manipulated by electricity. Where vast power is in constant demand for rolling rails and other heavy work, a monster steam-engine of the best type is in harness. To-day a twin engine driving a giant dynamo performs every other duty, displacing the many small engines which were formerly in charge of cranes, elevators, tilting-ladles, and the like, each of which is now driven by an electric motor, with remarkable economy. At the works of the Carnegie Steel Company at Homestead, Pennsylvania, the ores, fuel, and fluxes, as received from the mines, are unloaded, transported to the furnaces, hoisted, and discharged by a round of electric motors; while a succession of ladles, trucks, cranes, shapers, and saws, all actuated by electricity, complete the manufacture of the steel into beams. These are electrically laden upon railroad cars within twelve hours after the raw material is rolled into the yard. From first to last there is no direct touch by a human hand; the staff of the company confine their attention to giving effect to fingers of more than human grasp, strength, and endurance.

In the production of American pig-iron the cost of labour per ton fell about one-half in the ten years ending with 1897. A considerable part of that saving was due to the new electrical muscles which carry the burdens of an iron-mill almost as if weight were for the nonce abolished.

In ship-building not less than in metallurgy the electric motor is displacing the steam-engine. At Newport News, Virginia, the largest revolving derrick in the world is busy in a shipyard; it handles 150 tons for a diameter of 147 feet, and 70 tons for a diameter of 207 feet. Steamships and war-vessels offer a field in which the electric motor can abolish much waste, discomfort, and liability to damage. A large modern steamship contains, besides her main engines, 40 to 50 auxiliary engines, wasteful in their use of steam, and served by miles of piping, and hundreds of valves whose heat and leakages cause extreme discomfort and do much harm. These minor engines are attached to the anchor, the steering-gear, the boat-cranes, the deck-winches, the ice-machines, the ventilating-fans, ash-hoists, and the pumps; they work the dynamos which yield electric light. The *Darmstadt* and the *Prinz Heinrich* of the North German Lloyd Steamship Company are now equipped with electrically operated deck-winches instead of the familiar noisy donkey-engines. The later steamer *Bremen*, of the same line, is fitted with sixteen electric deck-cranes for handling cargo; they are noiseless in operation, and so simple that any stevedore can manage them with ease. Some of the new American battle-ships now building will have their turrets turned and their large guns loaded, served with ammunition, and trained by electricity.[1]

Great Engines Drive out Small.

What the marine engineer is beginning to do has already been done in some of the largest mining and metal-working establishments in the world. Electricity has made it profitable to unify motive power at a monster generating plant, since it provides a simple and instant means of distributing that power, not through the contracted dimensions of a ship, but over acres or even square miles. Power is much more cheaply produced in one big engine than in several small ones; motors do not need the constant attention demanded by steam-engines—the packing of piston-rods and valve-stems, the unremitting and costly lubrication. An engineer in front of a switchboard has ten times the directive control that he had before electricity gave his fingers a reach of miles, and conferred upon him the same mastery as the sweep of immediate vision.

All this is repeated and extended in the field of ordinary manufactures. A single huge engine has its power con-

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[1] "Electricity in Marine Work," S. Dana Greene, *Cassier's Magazine*, July, 1899.

verted into electricity by a dynamo, and the current carried throughout vast premises not only actuates the machinery, but supplies light, and such heat as may be needed, in making hats, for example. A like economy binds one small factory to another, and abolishes their local motive powers. Small steam-engines are very wasteful of fuel, and often require in proportion to power five times as much coal as the giants of the central stations. With these giants, therefore, is the victory. Note a report of their battle as it comes from a steam-boiler inspector of Philadelphia. He says that at the end of 1898 625 boilers out of a total of 3575 had been displaced by electric motors in that city. Wherever power is needed intermittently, or in small units, the electric motor has the field. An engine must have steam up all day, whether it is busy or idle; a motor goes off the pay-list the moment it stops work.

The Edison Electric Illuminating Company of New York had in November, 1899, as part of its output, about 30,000 horse-power in electric motors; many of these displaced steam- or gas-engines.

A Lighting Service Cheapens Motive Power.

In many cases a large electrical installation originally established mainly to furnish light, has found added profit in providing motive power during the hours when little or no light is in demand. At Montreal the Dominion Cotton Mills buy from the Royal Electric Company 3000 horse-power for the actuation of machinery, with the right to use the current until 7 P. M. in summer, and until 4 P. M. in winter. The mills are thus able to obtain power cheaper than from steam, while the electrical works can use their machinery, lines, and other equipment by day as well as by night.

The locomotive divides with the stationary engine the honours of fire as a source of motive power. So also with electricity: all its triumphs in the empire of manufacture are repeated in the realm of transportation. The first electrical railroad, 500 metres in length, was built for the Berlin Exhibition of 1879 by Siemens & Halske. Several other experimental lines followed, and in February, 1888, that of the Union Passenger Railway Company of Richmond, Virginia, proved itself the first important enterprise of the kind in America.[1] In its present form the construction of a street-car motor is a marvel of compactness and efficiency; its revolving armature (Fig. 52) has a core of laminated iron to avoid the waste of current suffered in the rings originally devised by Pacinotti and Gramme (Fig. 36).[2] Although the competition of electricity with the horse in this wide field is of so recent date, it is already near to complete victory—in America, at least. Only on short lines, and in a few small towns and villages, does the car-horse retain the foothold that once seemed so secure. In 1898, New York, following the lead of Budapest and Washington, adopted on a large scale the open-conduit system, which, in the circumstances of a huge traffic compressed within narrow limits, is much safer and better than an overhead-trolley line. At Chicago, the line to Englewood uses storage batteries for propulsion.

Electric Transportation.

Substantial reasons why electric traction of various types has made its way so fast are not far to seek. It is quicker than equine locomotion; the space occupied by horses is set free; their filth is banished; the injury to pavements from their iron-shod hoofs is done away with. It is the cheapest of all services, equine or other. A surface line in a populous city is best supplemented, as in Boston, by a subway,

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[1] A brief historical sketch appears as Chapter XII in *The Electric Railway in Theory and Practice*, by Oscar T. Crosby and Louis Bell. New York, W. J. Johnston Company.

[2] A detailed explanation of the motor of a street-car, fully illustrated, is given in Chapter IV of *Electric Street Railways*, by Edwin J. Houston and A. E. Kennelly. New York, W. J. Johnston Company.

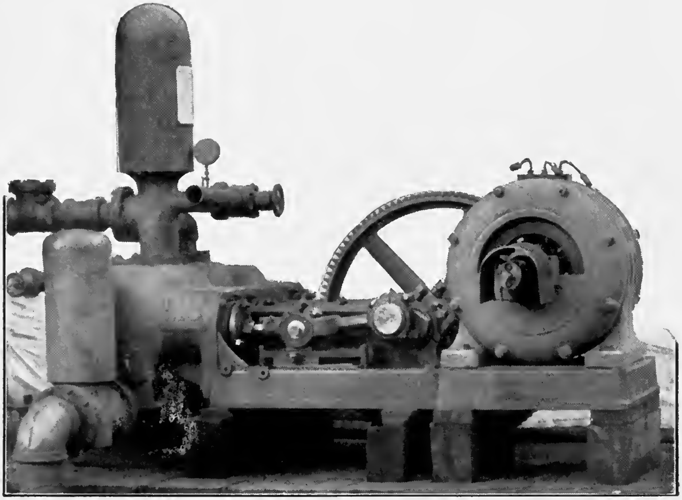

FIG. 51.

Worthington triplex pump, geared to 60 horse-power, 2080 volt induction motor. General Electric Co., Schenectady, N. Y.

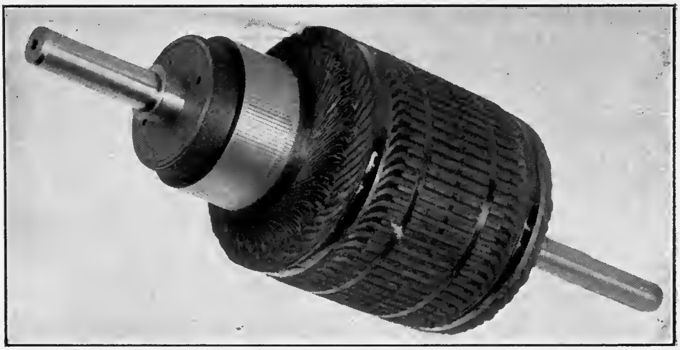

FIG. 52.

Armature for 5 horse-power direct-current motor. General Electric Co., Schenectady, N. Y.

or a tunnel, where there is no interruption by other traffic, and a speed is attainable quite out of the question above ground. Here, too, electricity is the best motive power. In London, the City and South London line, which runs beneath the Thames from Waterloo Station, has a suggestive advantage in its contour. As a train begins its journey the dip of the road gives it precisely the acceleration required; as the terminus is approached the train receives an equally desirable check as it climbs uphill. This contour may be usefully reproduced in the successive lengths of an underground road as it unites station to station, a benefit denied to an elevated line, which, perforce, must be level throughout. The new Central London underground route which connects Liverpool Street and Shepherd's Bush, six miles apart, is operated by electricity; its line is contoured as a series of gentle curves. Travellers who remember the soot and fumes of the original underground tunnel of London will rejoice that electrical propulsion has now been adopted for its lines.

Electric traction is a boon in the thronged streets of a metropolis; it works yet greater benefit when it traverses a city's gates and passes out into the suburbs. Having a pace double that of horses, it quadruples the area available for homes. In the older American cities the more central, narrow streets of residences are fast emptying themselves into districts where cheap land, modern architecture, and fresh air unite their persuasions. Between Albany and Troy, Minneapolis and St. Paul, Buffalo and Niagara Falls, the electric roads compete vigorously with the steam lines. Their cars run more frequently, they may be boarded anywhere through miles of streets, and they leave a passenger much nearer his destination than if he were landed at a railroad terminus. The consequence is that from each of these cities there stretches to its twin, avenue after avenue of dwellings surrounded by much of the comfort and wholesomeness of country life. Cleveland, Ohio, as the centre of a populous vicinage, and of rare commercial enterprise, can boast of the most remarkable network of electric lines in the world, amounting, in October, 1899, to no less than 434 miles, with Pittsburg, 150 miles off, as an objective point in the near future.

That the electric dynamo may act as a motor, and vice versa, has been noticed in Chapter VIII. On the Jungfrau Railway in Switzerland this is ingeniously turned to account. When the cars run downhill their wheels are made to generate a current, the motors serving as dynamos; this current takes its way into the line-wire for storage at headquarters.

One of the creations of the suburban trolley line is the excursion travel which pours out of American cities in all seasons, but especially, of course, during the height of summer. Every day, simply for the sake of the breeze caused by the motion of the car itself, a host of families leave the sun-baked streets for an hour's run in pure air. For longer excursions, affording visits to scenery of uncommon beauty or historic interest, there is ample opportunity in New England. "Its street-railways form the largest connected system in the world, running from Nashua, New Hampshire, on the north, through Boston to Newport and Providence, Rhode Island, on the south, a distance of 130 miles. Eastward they extend to the tip of Cape Ann, some 45 miles, and westward to West Warren, Massachusetts, some 80 miles."[1] Such a series of lines would lend itself to a charming variety of tours. All that is necessary is co-operation, so that through cars may be run of a thoroughly comfortable kind, and without loss of time as a passenger crosses the boundary of a particular road. It may be that for such a development as this the consolidations long ago effected in steam lines may be needful.

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[1] R. H. Derrah, *Street Railway Journal*, New York, July, 1899.

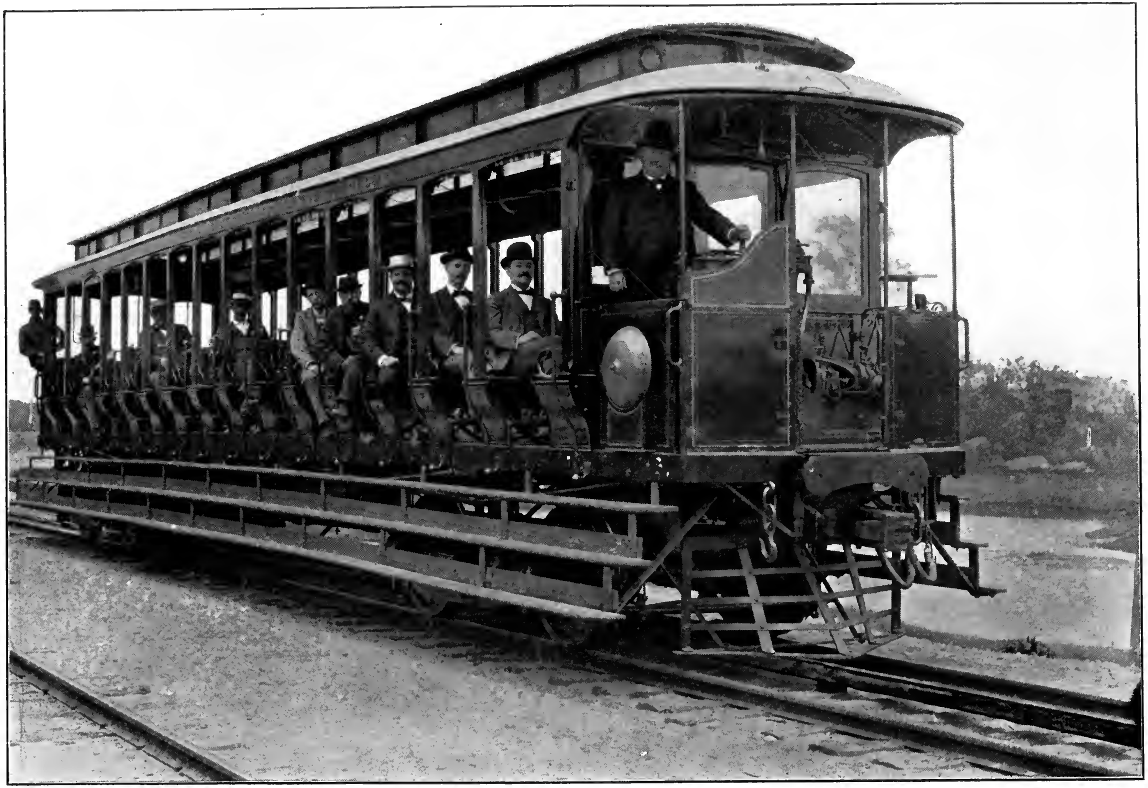

FIG. 53.

Third-rail system, New York, New Haven and Hartford Railroad

The Third-rail System.

While all this extension of electric traction has been pushed forward, the managers of steam lines have not been passive and uninterested spectators. The New York, New Haven and Hartford Railroad has inaugurated three electric lines with marked success, combining the trolley and third-rail systems for a total distance of 49 miles. In the third-rail method two rails, as usual, bear the car-wheels, a third, laid between them, serves to convey the current to a sliding bar or shoe attached to each car. Mr. N. H. Heft, chief of the electrical department of this railroad, states (November 10, 1899):

> During the summer months the Nantasket Beach service is extended on the main line to Braintree, alternating with the main-line electric service. This main-line service, which is the heaviest we now operate, consists in replacing the steam-locomotives by standard coaches equipped with four 175-horse-power motors, and hauling the same trains, of from two to five coaches, without change of schedule. We have under consideration the construction of other lines, both third-rail and trolley, the third-rail giving the better results wherever it is possible to operate it.

This third rail is easily and quickly laid. At one time all three rails on a section of the line were submerged by water, without interruption of the current. The third rail provides a conductor every whit as efficient as a large copper cable, and the escape of current from end to end of the line is but slight (Fig. 53).

Rivalry and its Probable Outcome.

In the light of such a success as this the query is prompted, Will electricity displace the steam-locomotive? The two sides of the ledger are easily compared. At a central station coals of inferior quality may be burned, or water-power harnessed, at the very minimum of cost. If high speed be wanted, the rotary motor can far outspin the reciprocating mechanism of steam. The pistons of the Empire State Express, between New

York and Buffalo, change their direction eight times a second, involving a tremendous strain on the metal. The debit side of the account displays the cost of fencing the line so as to prevent accidents from powerful currents; and the fact that, with a supply of power centralised at a single point, any derangement or accident works much more injury than when the units are independent of each other as self-moving machines. Reviewing these facts, the consensus of competent judges is that in sparsely settled regions through which the average locomotive takes its way it will keep its place. In thickly populated districts, such as surround a metropolis and are found in Massachusetts and Connecticut, it is likely that electricity will constantly strengthen its grasp.

The question is one of finance not less than of engineering. This is a time when the promoter of combination is in the saddle; we are likely very soon to see steam and electric interests lay down their arms and compose their differences. Each can supplement the other's deficiencies with profit to both. For short branches, where a locomotive would be absurdly underladen in hauling a car or two, an electric motor would come in as cheaper and better. On such lines the road-bed, bridges, and rolling stock could be lighter and less expensive than those of a steam line, and economically furnish a more frequent service. Where the trains are heavy and comparatively infrequent, the advantage remains with the old and ponderous steam-locomotive.

Electric Traction for Canals.

While increased economy of railroad engineering and operation has brought a severe competition to bear upon the canals, it is altogether probable that the cost of canal transportation will soon be reduced by the employment of the electric motor. It is expected that on the Erie Canal at least two hundred electric motors will be at work during 1900.

A Wider Market and Lower Prices.

Electric art has an interesting side to any one who has ever built or paid for an experimental model and contrasted its cost with that of a similar article manufactured at wholesale by machinery. As electrical engineering has passed from the experimental to the commercial stage, and that a stage of huge proportions, its economies have rapidly passed from little to much. First of all, its units of power have been vastly increased in size. Successive improvements in design, material, and arrangement unite in an efficiency simply astonishing when the last state of electric mechanism is compared with the first. As a consequence, price-lists have been steadily scaled down, except, temporarily, in such a year as 1899, when the metal market displayed so uncommon an advance. As dynamos, motors, and other machinery have gained in popular acceptance they have become cheaper, with the effect of broadening their acceptance yet more.

In 1884 a 50-kilowatt (67-horse-power) dynamo was considered a large machine. The General Electric Company at Schenectady, New York, has constructed several generators, each of 3500 kilowatts (4690 horse-power). These monsters have a three-phase revolving field with 40 poles, and run at a speed of 75 revolutions a minute, yielding a current of 6600 volts. In 1884 the price of dynamos was about 20 cents per watt ($\frac{1}{746}$ horse-power), while the price of the machine just mentioned is approximately but 1.2 cents per watt. The cost of generating a kilowatt ($1\frac{1}{3}$ horse-power) of electric energy from steam appears to have been at least 7.5 cents per horse-power in 1884. At the end of 1899 the cost of delivering for an hour a kilowatt to large street-railway systems from steam is only one cent, and the power-house operating costs are reported in some cases as low as half a cent. Electric energy from large water-powers has concurrently fallen in price in much the same ratio. In 1882 the price of a sixteen-candle lamp was about a dollar; in seventeen years the price has fallen to 20 cents in lots of a thousand, with special discounts to large consumers. During the same interval the price of plain carbons a foot long and half an inch in diameter, for arc-lamps, has dropped from $60 to $8.50 per thousand. The introduction of soft steel has been very advantageous to the electric-railway motor, enabling its output to be increased from 5 watts per pound of net weight, in 1884, to 12½ watts in the gearless, and 18½ in the geared, motors of the largest size manufactured by the General Electric Company at the end of 1899.

Evenness and Delicacy of Motion as Creators of Automatic Devices.

We have bestowed a glance upon electricity in its larger services to the engineer and mechanic as it impels the huge bulk of an express-train, or the mighty wheels of a steel-mill. Let us turn for a moment to the more delicate qualities of the current which commend it to the mechanician as he constructs and directs tools and instruments of consummate ingenuity. The perfect steadiness of the electric motor makes it indispensable to the phonograph, where the slightest jolting would make speech or music fall into a confused noise. Its flexibility is so exquisite that, revolving the surgeon's tiny saw, it equips him for operations of a new daring and refinement.

The current has characteristics even more valuable which spring from its positive action, however minute its quantity. In the telegraph at work over long distances this comes clearly into view. In days of yore, when letters were intrusted to a chain of messengers, each of whom bore the pouch for a stage of its journey, a carrier might come to the end of his trip utterly fagged out, but if he had the strength to pass his budget to the next man it was enough. The relays of olden times are curiously imitated in the relays of the telegraph. A feeble pulse from a distance is just strong enough to lift the armature of an electromagnet, but in doing so it brings one wire in contact with another and sends a strong local current into a second electromagnet, which may be as powerful as you please. Let us follow a telegram as it takes its way from Montreal to Vancouver — a distance of 2906 miles. First it goes to Fort William, at the head of Lake Superior, where the current, weak after its run of 998 miles, touches off instantly, through an automatic repeater, a second powerful current generated at Fort William. This, in turn, bears the despatch 937 miles to Swift Current, through another self-acting repeater. In like manner a third repeater at Swift Current sends the message 971 miles, for its final stage to Vancouver. The repeater is identical in principle with the telegraphic relay described and illustrated in the next chapter; given a proper succession of repeaters and it would be easy to belt the earth with a single electric circuit.

It is in pulling triggers in such fashion as this, in liberating and directing forces indefinitely greater than the initial impulse, that electricity confers upon muscles of brass and steel something very like a nervous system, so that the merest touch points the course of a steamship through the tempest-tossed Atlantic. Engineer, workman, and artist can thus reserve their strength for tasks more profitable than muscular dead lift, and find their sweep of initiation and control broadened to the utmost bound. In the field of war, for instance, a torpedo can be launched, propelled, steered, and exploded by a telegraph-key a mile or two away; the constructor may, indeed, confidently give all his orders in advance and build a torpedo which will fulfil a fate of both murder and suicide predetermined in its cams and magnets.

In the service of war and peace one would suppose the ordinary telegraph to be speedy enough. Not so, thinks the inventor. In one of the methods due to Mr. P. B.

Delany, a despatch wings its way from New York to Chicago at the rate of one thousand words a minute, to Philadelphia thrice as fast. The telegram is first taken to a machine which perforates each letter in symbols on a strip of paper, then the strip is run between a row of metallic springs of exquisite delicacy (Fig. 64). At each perforation the springs touch, and a momentary current is shot through the wire. At the receiving-station the delay involved in the arousal and motion of electromagnets is abolished. The current instant by instant writes its message on a moving ribbon of paper sensitised so as to change colour under an electric flow. This instance is typical of what ingenuity can do when electricity is added to its armoury. A task is divided between an operator and an automatic machine in such wise that intelligence is allotted only that part for which intelligence is required, while for the remaining part the utmost speed of electrical and chemical action is invoked—of a pace which, in this particular example, outstrips the most dexterous manipulation sixtyfold.

A census tabulator invented by Mr. Herman Hollerith of Washington, and adopted by the Census Bureau, exalts by a noteworthy step the quality of electrical work following mechanical initiation of the simplest. Imagine a census card divided into say two hundred spaces. John Smith's status is registered on such a card by punching holes in the squares assigned to Male, White, Native of New York, Reads and Writes, Lawyer, Married, and so forth. When the card bears the whole of its story it is laid upon a machine and a lid is pressed down. In the machine are two hundred needles, each corresponding on the card to a space which may or may not be punched. Wherever a needle meets a perforation it passes through and completes an electric circuit; each circuit moves a specific wheel one tooth forward, the Lawyer wheel, the Married wheel, or some other. Accordingly, if the Lawyer wheel, let us suppose, had borne the number 277 before it passed upon John Smith's card, that card now advances it to 278, which figure by a simple attachment may be printed as desired.

It was a great thought in numeration when the position of a figure became significant as well as the figure itself—when 1 began to mean 10, 100, or 1000 by a mere change of place. Mr. Hollerith's devices, in which position means so much, are now applied to railroad accounting and to the digestion of statistics. Their principle is that the particular place of a perforation among hundreds or thousands of others registers the accession of any fact represented in the mechanism, or any figure, however large. Machinery similar in principle is now employed instead of a mechanical Jacquard in weaving, and also in the movements of an experimental type-writer which, if successful, would lead the way to reducing the muscular effort of keyboard manipulations—now fast extending in the field of type-casting and kindred arts.

Instantaneity Made Useful.

All this and much other ingenious apparatus is created by electricity as an initiator of unrivalled delicacy; many other devices as remarkable have been born from the virtual instantaneity of its flight. Of this, of course, the supreme example is telegraphy. An illustration remarkable enough is the mechanism by which a hundred or more clocks in a city keep time together, minute by minute, or second by second. Two pendulums may swing in perfect step, no matter how many miles apart, and discharge duties much less simple than showing the hour. They may actuate the pencil which reproduces a portrait, or which writes an autograph, or which traces the devious course of a steamship as she skirts a thousand miles of coast. Some of the most noteworthy mechanism of telegraphy and the long-distance transmission of power involves the exquisite synchronism which no other agent but electricity can provide. On the South Side Elevated Railroad of Chicago each car has a motor of its own; any number of these cars may be joined as a train, since all the motors revolve with even step.

A current has the speed of light; it has also the ability of light to communicate impulses of broad range and great complexity. Ether bears to the eye luminous waves of widely various dimensions, each exciting the sensation of a particular hue all the way from red to violet. In the same fashion electric waves of most diverse contour may be committed to a wire in the full confidence that they will arrive at their destination without the slightest jostling or confusion. Proceeding upon this fact, Professor Elisha Gray devised his harmonic telegraph, perhaps with an inspiration due less to the phenomena of light than to those of music. If a tuning-fork be struck and held over the wires of a piano it will arouse to sympathetic vibration the wire which utters its own note, but none other. Each of the several messages in the harmonic system is sent into the telegraph line by a special tuning-fork, vibrated by an electromagnet. The composite tone, formed of the whole round of messages, as it arrives at the receiving-station, is resolved into its component tones by an array of harmonic plates, each attuned to one of the notes sent into the line. An ingenious device thereupon converts the signals into the ordinary Morse characters. When we come to consider the Marconi wireless telegraph we shall see how much it would be improved by the adoption of a harmonic method like this for its signals.

The electric clock at which we were looking a little while ago can, if we please, be sealed in a glazed box, secure from dust and dampness. It is seclusion like this which keeps electric motors free from the dirt and slush beneath a street-car, or preserves them aboard ship from attack by salt-laden air. Here opens a fresh path to the inventor who wishes to avoid the resistance or leakage entailed when a rod moves through a slot or a stuffing-box. It is often of cardinal importance that a bit of metal at rest should throb with a pulse strong enough to do severe drudgery, or tell a tale which otherwise would go untold. If an engineer wishes to know how much heat wastes itself through the walls of a steam-cylinder, his question is answered through a motionless wire attached to a delicate thermometer buried in the cylinder's mass. The same method informs the chemist experimenting with new alloys of changes often abrupt and fleeting, and at times denoting qualities he seeks to detain or reproduce.

A New Seclusion is Feasible.

A New Flexibility: Ether Replacing Wires.

As we prove when we unhook a telephone or lift an incandescent lamp, electricity readily traverses a flexible wire; this unbars a fresh gate to ingenuity. To-day rock-drills, coal-cutters, and deck-planers are designed in forms that combine motor and tool, actuated through wires as flexible as twine; so much is thereby gained in adaptability that much light machinery, rigidly limited in play by shafts, belts, or gearing, is being remodelled for use with electric power. Drilling-, slotting-, and milling-machines are now built in portable forms; they are brought to bear on large and heavy castings with an ease and convenience new in the machine-shop. Dentistry and other arts of refined manipulation are indebted for novel facilities to the flexible mechanical shaft—a tightly wound coil of steel wire. This contrivance is being shown to the door by the new partnership between an electric thread and a tool. Even the thread, however slender, which binds a reservoir of power to its work, can, on occasion, be discarded, as in the rolling contact of a trolley-wheel; and contact itself may be dispensed with if strict economy is not imperative, as we shall see by and by when we come to look at the Preece and Marconi plans of telegraphy without connecting wires.

The Echo of Intelligence.

Electricity, light, heat, and chemical action are all, in essence, motion; electricity is the most desirable of them all, because it can most readily and fully become the source of any other. The pre-eminent sensitiveness of electrical devices makes them a surpassing means of measuring minute portions of space or time, or of energy in its most elusive phases. Hence a brood of telltales of widely diversified purpose. Selenium, a metalloid of the same lineage as sulphur, and betraying its descent by a striking family resemblance, transmits electricity much more freely in light than in darkness. A stick of selenium, therefore, is the heart of a contrivance to give warning when extinction befalls a lamp charged with important duty, or to register the fluctuations of natural or artificial light.

In thermometers a circuit broken or completed acts as a fire-signal, or, on shipboard, heralds the approach of an iceberg. Electric fingers sound a gong when the water recedes below the safety limit in a steam-boiler, or report an attempted breach of bolt or bar by the burglar's jimmy. Each of these warnings can be registered at a distance, so that in case of neglect to heed them there can be no disputing the fact. Now, if an electric alarm can summon a servant to duty, why may not the inventor go farther, and so add to his device that it shall of its own motion do what needs to be done? Accordingly we find furnaces fitted up with electrical control, so that the draught is opened or fuel added when the temperature falls too low, or the draught is closed when the flame is too fierce; if the fuel is gas this automatic stoking leaves nothing to be desired.

In rough weather the propeller of a steamer is ever and anon lifted out of the water, and, thus relieved from work, dashes round at excessive speed, jarring itself and the ship dangerously as it dips again into the sea. A recent invention provides at the stern of the vessel an electrical lever which at the moment the ship "heels" throttles the steam-valve of the engine, and minimises both shock and hazard. New mechanism of this sort is constantly being contrived. The inventor who began by conferring electric nerves on muscles of brass and iron has, by grace of electricity, gone the length of combining his wires and magnets into something very like a conscious and responsive brain. His intelligence culminates in duplicating itself.

Electricity Broadens the Field of Mechanics.

All this has followed upon the mechanic's adding electricity to fire in the armoury of his resources. Flame acts directly within but a few inches at the farthest; its rays may be usefully transmitted for distances scarcely longer. The one mode of making it available to the mechanic is to build a heat-engine, and derive from its elastic gases a quantum of power which is never, at the most, but a modest fraction of the energy applied. An electric motor is incomparably simpler and more adaptable than a heat-engine, while thoroughly economical of the energy it receives. And mechanical motion, whether imparted to ropes, belts, or wires, has but narrow play—a mile or two at most. Convert this power into electricity and the field of transmission is multiplied fortyfold. And all this because a magnet has the unique quality of receiving molecular undulations not less swift than those of light, and translating them into the rotation of an armature that weighs tons and sweeps a circle measured in yards. Through this magic the electrical engineer commands mechanical motion which rises instantly to his touch, obeys his will minutely, traverses a stretch of a hundred miles with small subtraction as it goes, and swings a locomotive as easily as it lifts a silken thread.

This chapter has touched upon points so diverse that it may be permissible to recall them in a closing word. Common mechanical motion is profitably superseded by electricity because its conductor moves not as a mass, but in its molecules; the higher an electrical pressure, the narrower the path that it asks; electricity is readily changed in intensity; it makes a unit of a motor and a tool or machine; it brings automaticity to its utmost bound, so that human initiation is effective as never before; it is virtually a perfect fluid, so that a single centre of power may replace with economy a score, a hundred, or a thousand engines inherited from pre-electric days. In its more refined applications it has an evenness and a delicacy unknown prior to its introduction; it may be transmitted with full effect by the merest touch, or may perform its tasks at a distance, with no other medium than the universal ether; its pace is all but instantaneous, so that synchronism for the first time is available in apparatus scattered over a hundred leagues and more; its waves, as complex as those of light, nevertheless faithfully bear to a remote destination as intricate a series of impulses as those which stream from the sun. In every iota of these marvels the electric wave is in essence one and the same with the ray of flame, but how much has followed upon the ability to convert fire into a servant incomparably more versatile — which conquers a thousand provinces beyond the horizon of the fire-kindler, however far-sighted and bold!

CHAPTER XIII

TELEGRAPHY—LAND LINES

Precursors.

THE telegraph, one of the first pieces of mechanism to be actuated by electricity, may still be deemed the most important of all. For ages one of the principal uses of light was for the communication of intelligence; it may be many a long day before electricity is given a worthier task. In a previous chapter the employment of fire as a signaller was described, more especially as it served the aborigines of North America. In other parts of the world as ingenuity rose to new refinements the signals of a flame were diversified by changing its size, by separating blaze from blaze. When Troy fell before Agamemnon, in the eleventh century B. C., the news was borne to Clytemnestra, the spouse of the conqueror, by a chain of beacons stretching from Mount Ida to the palace of the queen at Mycenæ. Polybius, in the third century B. C., devised for service in the Punic Wars a simple telegraph in which an array of torches, by turns hidden and displayed, foreshowed the modern electric alphabet. That these torches might be replaced by shields or flags in the daytime does not seem to have occurred to any inventor for centuries, until, in 1680, Dr. Hooke, the famous English mechanician, devised an apparatus of coloured blocks, whose disposal was regulated by a pre-arranged code.

Across the Channel there was to be contrived in France a telegraph more ingenious still — nothing short of the parent of the semaphores which to this hour swing their coloured lanterns by night and arms by day over the tracks of railroads. Toward the end of the eighteenth century there were three brothers Chappé, all students, one at the Seminary of Angers, the other two at a private school a little more than a mile from the town. Claude, the seminarian, wishing to communicate with his brothers, fastened to a bar of wood two wing-pieces, movable at pleasure. He could thus produce signals clearly visible to the spy-glass of his brethren.

The first public exhibition of the contrivance took place in 1791; after the device had been materially improved it was adopted by the government of France, and, in 1793, brought from the frontier to Paris the news of the capture of Condé from the Austrians. In forms variously modified, the Chappé telegraph found its way to Denmark, Belgium, and Germany, to Sweden and Russia. On a plan specially adapted to the service of scouting and exploring parties, to travellers unable to cumber themselves with weighty apparatus, another group of inventors combined flags and streamers in such wise as to communicate with readiness and ease. This is the system common in the mercantile marine; it forms one of the diverse telegraphic resources of both armies and navies. A more important auxiliary in military manœuvres and in the service of the Weather Bureau, the heliograph, is much the most efficient device of its class. It employs a small mirror, so accurately surfaced and poised as to send a beam of light as far as twenty-five miles. Usually this beam is interrupted by the hand or a sheet of cardboard so as to spell out words in the Morse alphabetic code.

All these contrivances, old or new, suffer from serious restrictions. They are available for the most part only for short distances, comparatively speaking; they are useless when an object comes between the signal and the distant eye; in fog, or mist, or storm, they pass from sight. The light which gives direction or warning, declares distress, or tells a story, runs only in straight lines, which must suffer no interruption in their course, moderate though that course may be. When light gives place to her twin sister electricity, it is as if a ray were confined to a path no broader than a wire, and followed the metal through every twist and turning for miles. Sunshine or darkness, storm or calm, makes little difference to the electric throb; it bears a message as distinctly beneath the Atlantic as across a county. Little danger of signals being read by a foe when not only the means but the very fact of communication is concealed.

Pioneers.

The pioneers of electric telegraphy were many; we can recall only a few of them. In 1747 Dr. William Watson, in London, sent a flash through 12,276 feet of wire, and observed its transit to be instantaneous. This, however, was not telegraphy, but simply the proving that frictional electricity could be sent for a comparatively long distance. It was Le Sage of Geneva who, in 1774, constructed the first actual telegraph. He suspended twenty-four insulated wires, and apportioned a letter of the alphabet to each of them. To the end of every wire a pair of pith-balls was suspended. Whenever the opposite end of a line was in communication with the conductor of an electrical machine, the two balls of that line became similarly electrified and flew apart. Lomond of Paris saw how these twenty-four wires might be reduced to one wire by using a single pair of pith-balls and denoting each letter by a certain number of divergencies. An apparatus on the plan of signalling by sparks was set up by Salva, in Madrid, in 1798, and gave fair results over a line nearly half a mile in length. It was thus plainly demonstrated that an electric telegraph, for short distances at least, was perfectly feasible.

But the kind of electricity which thus far had been employed was suited only to experiments curious rather than useful. The lightning of a frictional machine sent into the wire was too extreme in its tension, and too minute in its quantity, for a really practical telegraph. To insulate the conducting metal for more than two miles or so was barely possible, while the impulses at the end of their journey were too much enfeebled to be trustworthy as signals. What was needed was the steady flow of electricity from dissolving metal, which Volta, in 1800, provided in the cells of his battery. In 1809 Sömmering applied the voltaic current for the first time in the service of a telegraph; but unfortunately he relied upon the power of the current to decompose water, and this slow process rendered his attempts of no avail. In 1816 Francis Ronalds erected a telegraph which used frictional shocks; his rare ingenuity thus misdirected came to nothing. Why, we may ask, did so able a man take an utterly wrong path? We should remember that at the time of Ronalds the identity of electricity from friction and from chemical solution was far from clear, and that until Daniell invented his cell, in 1836, there was no voltaic battery yielding a fairly constant stream.

Next in importance for telegraphy to the contrivance of the cell by Volta, and of its improved form by Daniell, was the discovery by Örsted, in 1820, of the deflection of a compass-needle as a current sped through a neighbouring wire. Here, to the clear eye of Ampère, was a means of receiving a message at once more forcible and trustworthy than any swing of the pith-balls of early experiment. Schweigger, also in 1820, discovered that the deflecting power of a current was multiplied when he wound a coil of wire round the needle instead of using a solitary wire.

He thus constructed the first galvanometer, an instrument since refined to the utmost delicacy as a measurer of extremely minute currents. When, four years later, Sturgeon invented the electromagnet a new and invaluable gift was handed to telegraphy as well as to other electric arts.

Practical Success.

Joseph Henry, in 1831, was engaged as a teacher at the Albany Academy, in Albany, New York, where, as we have already noted in a preceding chapter, he had much improved the electromagnet devised by Sturgeon. He now employed it for the first electromagnetic telegraph, which is thus described in his own words:

> I arranged, around one of the upper rooms in the Albany Academy, a wire of more than a mile in length, through which I was enabled to make signals by sounding a bell. The mechanical arrangement for effecting this object was simply a steel bar, permanently magnetised, of about ten inches in length, supported on a pivot, and placed with its north end between the two arms of a horseshoe magnet. When the latter was excited by the current, the end of the bar, thus placed, was attracted by one arm of the horseshoe and repelled by the other, and was thus caused to move in a horizontal plane, and its farther extremity to strike a bell suitably adjusted (Fig. 54).

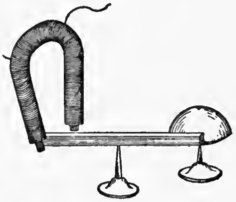

FIG. 54.
Henry telegraph.

In 1833 Professor Weber built a line of telegraph which, instead of being confined within the walls of a room, went forth into the open. It connected the Observatory of Göttingen with the Cabinet of Physics, and was about six thousand feet in length. The use of this line was purely in the interests of electrical science; the motions of its galvanometer were read not as a means of communication but as denoting how a current was affected by a journey through so long a conductor. In 1837 Steinheil built a line from the Royal Academy, Munich, to the Observatory, Bogenhausen, a distance of three miles. Felt was used as the insulator, and proved very defective. The first line constructed in England, two years later, was a success from the outset. It joined the Paddington Station of the Great Western Railway, in London, to West Drayton, thirteen miles off. Its designers, Wheatstone and Cooke, inclosed six copper wires in a wrought-iron tube an inch and a half in diameter, laid six inches above the ground alongside the railway. The wires within the tube were insulated from each other by a covering of hemp. In 1842 Cooke adopted the plan of suspending the wires on poles, and of insulating them by conical supports of stone or earthenware, soon discarded for porcelain and glass.

In America telegraphy still remained in the experimental stage. Morse, in 1832, conceived the idea of an electric telegraph, and, in complete ignorance of what Henry and other inventors had accomplished, began the making of instruments and experimental lines. In 1837 he exhibited the successful transmission of a message through 1700 feet of copper wire stretched about the walls of a room in the University of the City of New York, in Washington Square. In his further efforts Morse now associated himself with Alfred Vail, to whose ingenuity the alphabet known by the name of Morse is really due. As originally designed the telegraph of Morse transmitted only numerals, and these were interpreted by means of a dictionary whose words were numbered. In devising his alphabet, Mr. Vail consulted with the type-setters employed upon the local newspaper at his home, Morristown, New Jersey. They informed him that the most frequently used letter was *e*, and recognising that it should have the quickest made sign, he gave it a single dot. To the other letters he assigned the easiest made dot-and-dash characters in accordance with their relative frequency of use.[1]

In 1843, after a prolonged struggle, Congress voted Morse a grant of $30,000 wherewith to build an experimental line from the capital to Baltimore. The next year, on the completion of the work, a convincing proof was given of the value of electrical communication. The National Convention to nominate a President was sitting in Baltimore. James K. Polk had been nominated for the Presidency; Senator Silas Wright, then in Washington, for the Vice-Presidency. Mr. Vail telegraphed this to Mr. Morse, who immediately told Senator Wright. His response, forthwith transmitted to Baltimore, was a respectful declination. The convention could not believe the message to be authentic, and accordingly despatched a committee to Washington to confer with their nominee. The telegram was, of course, confirmed, and the fame of electricity as a messenger went the length and breadth of the Union.

Despite this triumph of the great initial experiment, there was disappointment in store for Morse and his fellow-workers. While the investigator and the inventor have their parts to play in the promotion of science and its application to the useful arts, the public, also, has something to do with the success of their toil. Without an enlightened demand for the telegraph all the labours of Morse, and of the predecessors from whom he inherited so much, would have been fruitless. On April 1, 1845, the line from Washington to Baltimore, which had been worked as a curiosity,

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[1] The code known as the Morse is as follows:

A . — B — . . . C . . . D — . . E . F . — . G — — . H . . . .

I . . J — . — . K — . — L —— M — — N — . O . . P . . . . .

Q . . — . R . . . S . . . T — U . . — V . . . — W . — —

X . — . . Y . . . . Z . . . . & . . . .

1 . — — . 2 . . — . . 3 . . . — . 4 . . . . — 5 — — —

6 . . . . . . 7 — — . . 8 — . . . . 9 — . . — 0 ——

was opened for public business. Its income for the first nine days of operation was $3.09½.[1] If the public had not soon awakened to what the telegraph stood ready to do for them, the enterprise would have perished in its cradle.

As lines were lengthened from the needs of experiment to meet the demands of commerce and the press, there arose important questions of mechanical detail, of disposal, and of insulation. In Chapter XII a word was said about the high value of a feeble current as it starts off currents vastly stronger than itself, much as if a giant at the touch of a babe delivered a tremendous blow. In a telegraphic relay, the arriving impulse, very weak though it may be, is still equal to making one wire touch another, thus bringing into play a powerful local current,

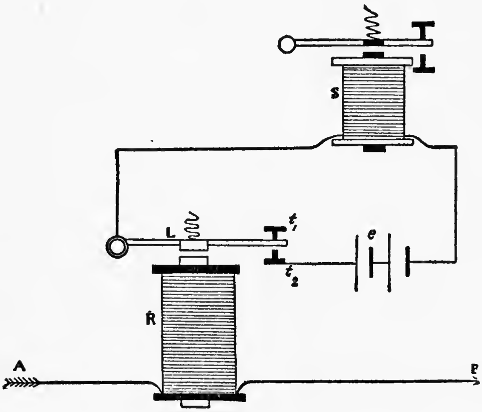

Fig. 55.
Telegraph relay.

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[1] During the first four days the receipts amounted to one cent. This was obtained from an office-seeker, who said that he had nothing else than a twenty-dollar bill and one cent, and, with the modesty of his class, wanted to see the operation free. This was refused because against orders. He was then told that he could have a cent's worth of telegraphy, to which he agreed. He was gratified in the following manner: Washington asked Baltimore, "4 ?" which meant in the list of signals, "What time is it?" Baltimore replied, "1," which meant, "One o'clock." This was one character each way, which, according to the tariff, would amount to half a cent. The man paid his one cent, declined the change, and went his way. This was the revenue for four days. On the fifth 12½ cents were received. The sixth was the Sabbath. On the seventh the revenue ran up to 60 cents. On the eighth to $1.32. On the ninth they were $1.04.—James D. Reid, *The Telegraph in America.* New York, 1886.

which either speeds a message for a farther stage of its journey, or actuates a local sounder which utters the message in loud, unmistakable tones (Fig. 55). The armature lever *L* plays between two stops, t_1, t_2, under the influence of attraction by the electromagnet *R* and the retractile spiral spring. When attracted by *R*, the lever closes the circuit, through the local battery *e*, the stop t_2, and the sounder *S*. *AB* is the main-line circuit.

Discovery as well as invention has smoothed the path of telegraphy. In 1872 Joseph B. Stearns showed how a single wire can bear two messages at once; on trunk-lines, always busy, he thus cut down the cost of wires by one-half. His method will be described in Chapter XV. Thirty-six years before his achievement a remarkable discovery reduced in the same proportion all wires, whether those of main lines or any other. In 1838 Steinheil experimented on the line of the Nürnberg-Fürther Railroad with a view to ascertaining if the track could be used instead of one of the two ordinary telegraphic wires. He observed that the current passed from one rail to another through the earth. It occurred to him that it might be feasible to use the ground itself as the return half of a circuit and thus dispense with the costly return wire. An experiment, forthwith entered upon, satisfied him of the correctness of his surmise. Before this great discovery every telegraphic circuit had demanded two complete lengths of wire, both connected to the instruments at the ends of a line. Ever since Steinheil's decisive experiment broad plates or sheets of metal buried in the ground, and attached to both ends of a line, have taken the place of the long and costly second wire once deemed indispensable (Fig. 56).

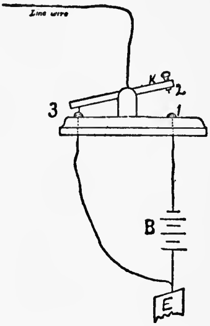

FIG. 56.
Grounding a circuit.

The telegraph-key *K* in its normal position is kept in contact with stop 3 by means of a spring, and thus maintains the line-wire in connection with the earth through the plate *E*. When the key is depressed 2 is brought into contact with 1, and the current from the battery *B* sends a signal through the line.

How best to dispose the wires of a telegraph was not at first very clear. For the inaugural line from Washington to Baltimore Morse began by adopting the plan of burying his wires, covered with cotton and shellac, and drawn through lead pipes. When ten miles of this cable had been laid it proved a total failure. At the instance of Ezra Cornell, the wires were now placed on poles, after the fashion introduced by Cooke in England. The result was a gratifying success. Year by year much was learned as aerial wires were compared with subterranean—for in some cases, as in railroad tunnels and the like, it was necessary to carry wires underground. It was ascertained that the air retarded a signal scarcely at all, while the earth held it back perceptibly if the line were long. This early study of induction had important developments, as we shall presently see when we consider telegraphic wires submerged beneath the Atlantic Ocean.

Insulation, too, was a matter of moment from the first. Cornell's original insulators were small pieces of common window-glass, which he fastened above and below a wire (Fig. 57). Retaining the material, the form was soon changed for the conical shape now familiar. In England, where the damp air readily deposits moisture on glass, porcelain was soon introduced, and has now won its way the world over. At this point we may note a singular analogy between light and electricity. Sunshine at high noon is blocked by a sheet of iron no thicker than tissue-paper.

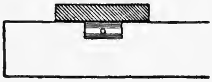

FIG. 57.
First glass insulator.

The opacity of the metal to the solar ray is paralleled by the imperviousness of glass to the electric pulse. Mr. A. E. Kennelly says that glass at ordinary temperatures is roughly ten thousand millions of millions of millions of times more resistant than copper. It is plain that although, in some degree or other, all substances are conductors, their quality is apt to be extreme in either goodness or badness. And we must not miss the fact that glass, which transmits light so well, obstructs electricity almost perfectly. Light consists in waves which vary little from $\frac{1}{40000}$ of an inch in length; electric waves may be millions or even billions of times longer; from this difference in dimensions may arise their highly contrasted powers of penetration.

Small though the loss at a single insulator on a telegraph-pole may be, that loss on a long line is multiplied by a high figure. If there are twenty-five poles to a mile, there are twenty-five thousand insulators on a stretch of a thousand miles, and their leakage in the aggregate plainly limits any single telegraphic circuit. In lengthening circuits, much has been done by improving the quality of the conductor. Iron, which is in common use for comparatively short lines, has the merit of cheapness; moreover, when galvanised, or coated with zinc, it resists atmospheric corrosion. The advantage, too, of either iron or steel is that its great tensile strength permits the engineer to place his poles at twentieths of a mile on minor lines, thus reducing the number of insulators at which the current may escape. Of course, it was known at the outset of telegraphic practice that copper is a much better conductor than iron, and in no less a degree than sixfold. But copper as manufactured in those early days was impure, and the trace of arsenic which it sometimes held lowered its conductivity as much as two-fifths. Thanks, however, to electrolytic deposition, copper is now produced in all but absolute purity, while, through a suggestion of Mr. T. B. Doolittle of Boston, it is hard drawn so as to compete with iron in strength without sacrifice of conducting quality. Hence it is that we have today copper telegraphic circuits a thousand miles in extent, whereas four hundred miles is the longest stretch possible to iron. The copper circuit of 1000 miles has a resistance of but 4 ohms; an iron circuit of 400 miles has a resistance of 19 ohms. For important trunk-lines it is deemed an advantage to employ the comparatively dear metal from its high efficiency and small liability to accident.

The Gifts of the Telegraph.

Within a few weeks after its installation as a public servant both in Europe and America, the electric telegraph began its career as one of the chief resources of civilised man. It was almost as if he could make his voice heard at the ends of the earth; there was all the gain that comes from knowing an event of importance at once instead of only after a messenger has finished a journey of days, or weeks, or even months. Incalculable were the alleviations of suffering and distress which at once became possible. When a threatening illness demanded the aid of a distant physician or surgeon, he could be summoned without the delay of a moment. If cholera, or other pest, invaded a port, the neighbouring country could be apprised forthwith, and set up its defences unperturbed by panic.

In uncounted minor services the anxieties and suspense common in a former age are banished by the telegraph. The minute that a steamer comes near Sandy Hook, or Southampton, the news may be communicated to a passenger's family; if an invalid goes to southern California, or to Italy, his friends in the North may have a daily bulletin of his health as new scenes and balmy air work their restoration. In a thousand ways the telegraph gives us new safeguards against accident and loss of life. A sudden ice-shove covers the track of a bridge over the St. Lawrence; instantly a despatch prevents a train from entering the structure. A steamboat is about to put out to sea at its usual hour; word comes from the Weather Bureau that the storm which seems but moderate is likely to rise to fury in a few hours; the captain heeds the warning, and escapes destruction for himself, his passengers, and his crew.

Less important, but quite as striking, are the benefits which the telegraph confers by making human effort more efficient than when it was ignorant of facts bearing vitally upon the gainfulness of its tasks. A vessel is despatched from Yokohama to San Francisco, and whither it shall next turn its prow depends upon instructions from the owners in Liverpool. It may carry harvesting-machinery to Sydney, New South Wales, or take a cargo of wheat to Glasgow. A cotton-mill in Massachusetts is destroyed by fire. Before the hose has ceased to play upon its smoking walls new looms are being packed in Lancashire to take the first steamer to Boston. The owner of that mill, as he scans his newspaper every morning and night, can learn to the hundredth part of a cent how much his raw cotton will cost him if he buys it now, to meet in advance nearly a year's requirement. Quotations of "futures" such as these are possible because thousands of observers in the cotton belt, the iron regions, the copper country, are telegraphing their reports day by day to the exchanges of the world. Money, to-day, has all the fluidity of electricity itself. Across national frontiers, or divided by the breadth of half the planet, bankers are in the closest touch. If money is scarce in London, New York extends immediate aid; if Berlin or Amsterdam offers a new loan, investors in Chicago and Philadelphia may subscribe as soon as if they dwelt in the German or the Dutch capital. Modern wars dismiss through the telegraph one of the horrors incident to ancient modes of communication. Before electric telegraphy it sometimes happened that battles were fought days, or even weeks, after a formal treaty of peace had been signed by the principals concerned.

Let us note a typical case or two of the economic revolution wrought by the telegraph. A manufacturer of tweeds in Scotland sends his travelling agents to every quarter of the globe, and requires them, on occasion, to supplement their letters with despatches which may mean a sentence in a word—thanks to the ingenuity of code-makers. He thus avoids weaving so much as a single yard of cloth for chance sale, and the cost and risk of keeping a large variety of goods for inspection is abolished. The same method it is which more and more puts the small premises of the commission agent, with its cupboard of samples, where stood the large and expensive warehouse which was formerly the sole means of bringing together the manufacturer and the merchant.

In a field indefinitely broader the master of a great industry—iron-mining, steel-making, the refining of oil or sugar—is seated at the centre of a vast web, from which he observes and regulates a thousand subordinates, and makes the rill of gain that each creates converge with the utmost directness into one huge reservoir. It is the telegraph which gives a thousand facets to the eyes of such a man as this, and enables him to act the part of a leader to an orchestra of stupendous proportions and diversity. We must bear in mind that often the more comprehensive a business becomes the simpler it grows in important respects. If one concern operates a mine, and another works up the iron from its ore into bars, rails, and plates, there is abundant opportunity for misunderstandings and maladjustments between the two. All these disappear when the two concerns unite. Under a single chief a falling off in the demand for rails will be immediately reflected in the reduced pay-roll of the mine. If a wire-mill has been included in the combination, an active market for wire will lead at once to a score or a hundred hands being brought into that mill from some other department of the works. Between every subdivision of the business there will be complete harmony, with the result that products will be created and distributed at lower cost than before.

By an industrial king sufficiently able the whole Union, or even the world itself, may be organised as a single market, whose wants may be systematically ascertained, and as systematically supplied from the trade centre of each territorial division. With the undisputed control of such a business credit is not unduly cheapened, as when competition runs riot, and indeed credit may be totally abolished; in either case one of the chief perplexities of ordinary trade—the estimation of risks—disappears from the manager's mind. By a unification of control, backed by abundant capital, any new improvement in machinery or process is introduced at once throughout every ramification of the central control. From first to last it is the telegraph which gives regimentation to such an enterprise as this, so that at last the economy which electricity confers upon production is paralleled by the saving it affords to distribution.

"To him that hath shall be given" takes on a new force when industrial and financial might thus add to the wings of the wind and the hot breath of steam the lightning courser of Wheatstone and Morse. We have noticed in a previous chapter how profitable are the consolidations of power inaugurated in the engine-room and machine-shop by the wand of the electrician; we now see that his work is equally gainful in the empire of commerce and trade. The streams of production and of transportation at his bidding take on all the fluidity of the agent he employs. That mills, refineries, and factories have come to the end of their consolidations no competent observer believes. The process, when wisely ordered, is as much in the line of economy as the division of labour in cotton manufacture, which came in with Arkwright and Watt. Now that to the old heat-engines is added the might conferred by the new servant, electricity, there arises no such minor question as that of bringing to accord the various tasks of the operatives under a single roof, but, instead, a larger problem, nothing less than the sweeping unification of a whole industry, represented though it may be in a thousand manufacturing concerns. Here physics and politics touch hands. How, we may ask, are the powers of the trusts and consolidated railroads to be restrained from tyranny and exaction? A pressing difficulty of the hour, mainly created by the electric wire, is how the advantages of complete industrial organisation may be enjoyed by the public without the oppressions of irresponsible power.

The telegraph has another typical field free from perplexity, and in the main one of benefit unalloyed. Mark the news columns of the press as they make the world a whispering-gallery and broaden the provincial view to the comprehension of the globe. The speeches of Parliament at Westminster are in the hands of readers in New York before the speakers have gone to their beds. The wrongs of the Armenian and the Finn, the explorations of old Egypt, and the voyages toward the antarctic pole are discussed together with the news of the county and the ward. The applause won by an American prima donna at the opera in Paris or Dresden, the reception of the American ambassador as he is greeted by Queen Victoria at Windsor Castle, the progress toward confederation in the colonies of Australasia, all become part and parcel of the gossip of tea-tables in Wisconsin and Vermont. Thus there springs up that comity of nations which is so little furthered by an obvious wooing, and that declines to be promoted by the arguments of the Peace Society—for all the pathos of their appeal.

CHAPTER XIV

CABLE TELEGRAPHY

ELECTRIC telegraphy on land has put a vast distance between itself and the apparatus of Chappé, just as the scope and availability of the French invention are in high contrast with the rude signal-fires of the primitive savage. As the first land telegraphs joined village to village, and city to city, the crossing of water came in as a minor incident; the wires were readily committed to the bridges which spanned streams of moderate width. Where a river or inlet was unbridged, or a channel was too wide for the roadway of the engineer, the question arose, May we lay an electric wire under water? With an ordinary land line, air serves as so good a non-conductor and insulator that as a rule cheap iron may be employed for the wire instead of expensive copper. In the quest for non-conductors suitable for immersion in rivers, channels, and the sea, obstacles of a stubborn kind were confronted. To overcome them demanded new materials, more refined instruments, and a complete revision of electrical philosophy.

Beginnings at New York and Dover.

As far back as 1795, Francisco Salva had recommended to the Acádemy of Sciences, Barcelona, the covering of subaqueous wires by resin, which is both impenetrable by water and a non-conductor of electricity. Insulators, indeed, of one kind and another, were common enough, but each of them was defective in some quality indispensable for success. Neither glass nor porcelain is flexible, and therefore to lay a continuous line of one or the other was out of the question. Resin and pitch were even more faulty, because extremely brittle and friable. What of such fibres as hemp or silk, if saturated with tar, or some other good non-conductor? For very short distances under still water they served fairly well, but any exposure to a rocky beach with its chafing action, any rub by a passing anchor, was fatal to them. What the copper wire needed was a covering impervious to water, unchangeable in composition by time, tough of texture, and non-conducting in the highest degree. Fortunately all these properties are united in gutta-percha and in nothing else known to art. Gutta-percha is the hardened juice of a large tree (*Isonandra gutta*) common in the Malay Archipelago; it is tough and strong, easily moulded when moderately heated. In comparison with copper it is but $\frac{1}{60,000,000,000,000,000,000}$ as conductive. As without gutta-percha there could be no ocean telegraphy, it is worth while recalling how it came within the purview of the electrical engineer.

In 1843 José d'Almeida, a Portuguese engineer, presented to the Royal Asiatic Society, London, the first specimens of gutta-percha brought to Europe. A few months later, Dr. W. Montgomerie, a surgeon, gave other specimens to the Society of Arts, of London, which exhibited them; but it was four years before the chief characteristic of the gum was recognised. In 1847 Mr. S. T. Armstrong of New York, during a visit to London, inspected a pound or two of gutta-percha, and found it to be twice as good a non-conductor as glass. The next year, through his instrumentality, a cable covered with this new insulator was laid between New York and Jersey City; its success prompted Mr. Armstrong to suggest that a similarly protected cable be submerged between America and Europe. Eighteen years of untiring effort, impeded by the errors inevitable to the pioneer, stood between the proposal and its fulfilment. In 1848 the Messrs. Siemens laid under water in the port of Kiel a wire covered with seamless gutta-percha, such as, beginning with 1847, they had employed for subterranean conductors. This particular wire was not used for telegraphy, but formed part of a submarine-mine system. In 1849 Mr. C. V. Walker laid an experimental line in the English Channel; he proved the possibility of signalling for two miles through a wire covered with gutta-percha, and so prepared the way for a venture which joined the shores of France and England.

In 1850 a cable 25 miles in length was laid from Dover to Calais, only to prove worthless from faulty insulation, and the lack of armour against dragging anchors and fretting rocks. In 1851 the experiment was repeated with success. The conductor now was not a single wire of copper, but four wires, wound spirally so as to combine strength with flexibility; these were covered with gutta-percha and surrounded with tarred hemp. As a means of imparting additional strength, ten iron wires were wound round the hemp—a feature which has been copied in every subse-

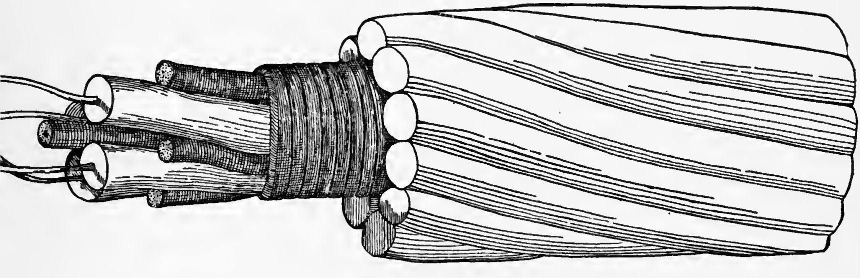

Fig. 58.
Calais-Dover cable, 1851.

quent cable (Fig. 58). The engineers were fast learning the rigorous conditions of submarine telegraphy; in its essentials the Dover-Calais line continues to be the type of deep-sea cables to-day. The success of the wire laid across the British Channel incited other ventures of the kind. Many of them, through careless construction or unskilful laying, were utter failures. At last, in 1855, a submarine line 171 miles in length gave excellent service, as it united Varna with Constantinople; this was the greatest length of satisfactory cable until the submergence of an Atlantic line.

The Atlantic Cable.

In 1854 Cyrus W. Field of New York opened a new chapter in electrical enterprise as he resolved to lay a cable between Ireland and Newfoundland, along the shortest line that joins Europe to America. He chose Valentia and Heart's Content, a little more than 1600 miles apart, as his termini, and at once began to enlist the co-operation of his friends. Although an unfaltering enthusiast when once his great idea had possession of him, Mr. Field was a man of strong common sense. From first to last he went upon well-ascertained facts; when he failed he did so simply because other facts, which he could not possibly know, had to be disclosed by costly experience. Messrs. Whitehouse and Bright, electricians to his company, were instructed to begin a preliminary series of experiments. They united a continuous stretch of wires laid beneath land and water for a distance of 2000 miles, and found that through this extraordinary circuit they could transmit as many as four signals per second. They inferred that an Atlantic cable would offer but little more resistance, and would therefore be electrically workable and commercially lucrative.

In 1857 a cable was forthwith manufactured, divided in halves, and stowed in the holds of the *Niagara* of the

United States navy, and the *Agamemnon* of the British fleet. The *Niagara* sailed from Ireland; the sister ship proceeded to Newfoundland, and was to meet her in mid-ocean. When the *Niagara* had run out 335 miles of her cable it snapped under a sudden increase of strain at the paying-out machinery; all attempts at recovery were unavailing, and the work for that year was abandoned. The next year it was resumed, a liberal supply of new cable having been manufactured to replace the lost section, and to meet any fresh emergency that might arise. A new plan of voyages was adopted: the vessels now sailed together to mid-sea, uniting there both portions of the cable; then one ship steamed off to Ireland, the other to the Newfoundland coast. Both reached their destinations on the same day, August 5, 1858, and, feeble and irregular though it was, an electric pulse for the first time now bore a message from hemisphere to hemisphere. After 732 despatches had passed through the wire it became silent forever. In one of these despatches from London, the War Office countermanded the departure of two regiments about to leave Canada for England, which saved an outlay of about $250,000. This widely quoted fact demonstrated with telling effect the value of cable telegraphy.

The Ordeal of Failure.

Now followed years of struggle which would have dismayed any less resolute soul than Mr. Field. The Civil War had broken out, with its perils to the Union, its alarms and anxieties for every American heart. But while battleships and cruisers were patrolling the coast from Maine to Florida, and regiments were marching through Washington on their way to battle, there was no remission of effort on the part of the great projector.

Indeed, in the misunderstandings which grew out of the war, and that at one time threatened international conflict, he plainly saw how a cable would have been a peace-maker. A single word of explanation through its wire, and angry feelings on both sides of the ocean would have been allayed at the time of the Trent affair. In this conviction he was confirmed by the English press; the London *Times* said: "We nearly went to war with America because we had no telegraph across the Atlantic." In 1859 the British government had appointed a committee of eminent engineers to inquire into the feasibility of an Atlantic telegraph, with a view to ascertaining what was wanting for success, and with the intention of adding to its original aid in case the enterprise were revived. In July, 1863, this committee presented a report entirely favourable in its terms, affirming "that a well-insulated cable, properly protected, of suitable specific gravity, made with care, tested under water throughout its progress with the best-known apparatus, and paid into the ocean with the most improved machinery, possesses every prospect of not only being successfully laid in the first instance, but may reasonably be relied upon to continue for many years in an efficient state for the transmission of signals."

Taking his stand upon this indorsement, Mr. Field now addressed himself to the task of raising the large sum needed to make and lay a new cable which should be so much better than the old ones as to reward its owners with triumph. He found his English friends willing to venture the capital required, and without further delay the manufacture of a new cable was taken in hand. In every detail the recommendations of the Scientific Committee were carried out to the letter, so that the cable of 1865 was incomparably superior to that of 1858. First, the central copper wire, which was the nerve along which the lightning was to run, was nearly three times larger than before. The old conductor was a strand consisting of seven fine wires, six laid round one, and weighed but 107 pounds to the mile. The new was composed of the same number of wires, but weighed 300 pounds to the mile. It was made of the finest copper obtainable.[1]

To secure insulation, this conductor was first embedded in Chatterton's compound, a preparation impervious to water, and then covered with four layers of gutta-percha, which were laid on alternately with four thin layers of Chatterton's compound. The old cable had but three coatings of gutta-percha, with nothing between. Its entire insulation weighed but 261 pounds to the mile, while that of the new weighed 400 pounds.[2] The exterior wires, ten in number, were of Bessemer steel, each separately wound in pitch-soaked hemp yarn, the shore ends specially protected by 36 wires girdling the whole. Here was a combination of the tenacity of steel with much of the flexibility of rope. The insulation of the copper was so excellent as to exceed by a hundredfold that of the core of 1858—which, faulty though it was, had, nevertheless, sufficed for signals. So much inconvenience and risk had been encountered in dividing the task of cable-laying between two ships that this time it was decided to charter a single vessel, the *Great Eastern*, which, fortunately, was large enough to accommodate the cable in an unbroken length. Foilhommerum Bay, about six miles from Valentia, was selected as the new Irish terminus by the company. Although the most anxious care was exercised in every detail, yet, when 1186 miles had been laid, the cable parted in 11,000 feet of water, and although thrice it was grappled

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[1] The Gutta-percha Company of London manufactured the copper core and gutta-percha covering of the cable of 1858; the outer sheathing was furnished by Glass, Elliot & Co. of Greenwich and R. S. Newall & Co. of Birkenhead. The cables of 1865 and 1866 were manufactured at Greenwich by the Telegraph Construction and Maintenance Company, formed from the Gutta-percha Company and Glass, Elliot & Co.

[2] Henry M. Field, *History of the Atlantic Telegraph.* New York, Scribner, 1866.

and brought toward the surface, thrice it slipped off the grappling hooks and escaped to the ocean floor.

The Triumph of Courage.

Mr. Field was obliged to return to England and face as best he might the men whose capital lay at the bottom of the sea—perchance as worthless as so much Atlantic ooze. With heroic persistence he argued that all difficulties would yield to a renewed attack. There must be redoubled precautions and vigilance never for a moment relaxed. Everything that deep-sea telegraphy has since accomplished was at that moment daylight clear to his prophetic view. Never has there been a more signal example of the power of enthusiasm to stir cold-blooded men of business; never has there been a more striking illustration of how much science may depend for success upon the intelligence and the courage of capital. Electricians might have gone on perfecting exquisite apparatus for ocean telegraphy, or indicated the weak points in the comparatively rude machinery which made and laid the cable, yet their exertions would have been wasted if men of wealth had not responded to Mr. Field's renewed appeal for help. Thrice these men had invested largely, and thrice disaster had pursued their ventures; nevertheless they had faith surviving all misfortunes for a fourth attempt.

In 1866 a new company was organised, for two objects: first, to recover the cable lost the previous year and complete it to the American shore; second, to lay another beside it in a parallel course. The *Great Eastern* was again put in commission, and remodelled in accordance with the experience of her preceding voyage. This time the exterior wires of the cable were of galvanised iron, the better to resist corrosion. The paying-out machinery was reconstructed and greatly improved. On July 13, 1866, the huge steamer began running out her cable twenty-five miles north of the line struck out during the expedition of 1865; she arrived without mishap in Newfoundland on July 27, and electrical communication was re-established between America and Europe. The steamer now returned to the spot where she had lost the cable a few months before; after eighteen days' search it was brought to the deck in good order. Union was effected with the cable stowed in the tanks below, and the prow of the vessel was once more turned to Newfoundland. On September 8 this second cable was safely landed at Trinity Bay. Misfortunes now were at an end; the courage of Mr. Field knew victory at last; the highest honours of two continents were showered upon him.

> 'T is not the grapes of Canaan that repay,
> But the high faith that failed not by the way.

A Highway Smoothed for Successors.

What at first was as much a daring adventure as a business enterprise has now taken its place as a task no more out of the common than building a steamship, or rearing a cantalever bridge. Given its price, which will include too moderate a profit to betray any expectation of failure, and a responsible firm will contract to lay a cable across the Pacific itself. In the Atlantic lines the uniformly low temperature of the ocean floor (about 4° C.), and the great pressure of the superincumbent sea, cooperate in effecting an enormous enhancement both in the insulation and in the carrying capacity of the wire. As an example of recent work in ocean telegraphy let us glance at the cable laid in 1894, by the Commercial Cable Company of New York. It unites Cape Canso, on the northeastern coast of Nova Scotia, to Waterville, on the southwestern coast of Ireland. The central portion of this cable much resembles that of its predecessor in 1866. Its exterior armour of steel wires is much more elaborate. The first part of

Fig. 59 shows the details of manufacture: the central copper core is covered with gutta-percha, then with jute, upon which the steel wires are spirally wound, followed by a strong outer covering. For the greatest depths at sea, type *A* is employed for a total length of 1420 miles; the diameter of this part of the cable is seven-eighths of an inch. As the water lessens in depth the sheathing increases in size until the diameter of the cable becomes $1\frac{1}{16}$ inches for 152 miles, as type *B*. The cable now undergoes a third enlargement, and then its fourth and last proportions are presented as it touches the shore, for a distance of $1\frac{3}{4}$ miles, where type *C* has a diameter of $2\frac{1}{2}$ inches. The weights of material used in this cable are: copper wire, 495 tons; gutta-percha, 315 tons; jute yarn, 575 tons; steel wire, 3000 tons; compound and tar, 1075 tons; total, 5460 tons. The telegraph-ship *Faraday*, specially designed for cable-laying, accomplished the work without mishap.

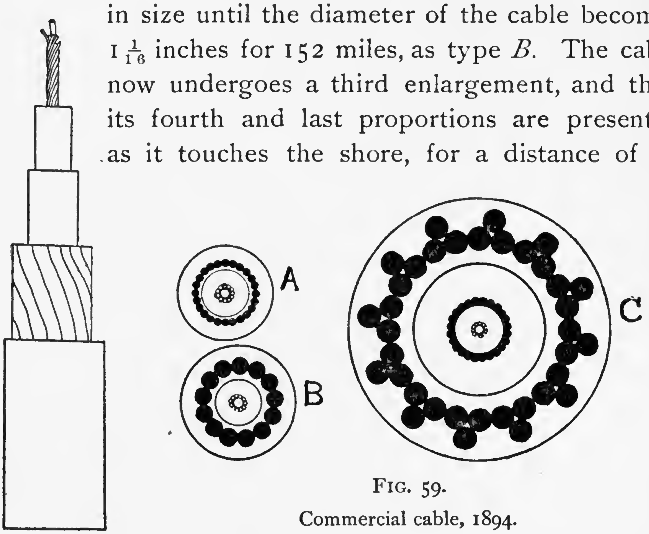

FIG. 59.
Commercial cable, 1894.

Electrical science owes much to the Atlantic cables, in particular to the first of them. At the very beginning it banished the idea that electricity as it passes through metallic conductors has anything like its velocity through free space. It was soon found, as Professor Mendenhall says, "that it is no more correct to assign a definite velocity to

Lessons of the Cable.

electricity than to a river. As the rate of flow of a river is determined by the character of its bed, its gradient, and other circumstances, so the velocity of an electric current is found to depend on the conditions under which the flow takes place."[1] Mile for mile the original Atlantic cable had twenty times the retarding effect of a good aerial line; the best recent cables reduce this figure by nearly one-half.

In an extreme form this slowing down reminds us of the obstruction of light as it enters the atmosphere of the earth, of the further impediment which the rays encounter if they pass from the air into the sea. In the main the causes which hinder a pulse committed to a cable are two: induction, and the electrostatic capacity of the wire, that is, the capacity of the wire to take up a charge of its own, just as if it were the metal of a Leyden jar.

Let us first consider induction. As a current takes its way through the copper core it induces in its surroundings a second and opposing current. For this the remedy is one too costly to be applied. Were a cable manufactured in a double line, as in the best telephonic circuits, induction, with its retarding and quenching effects, would be neutralised. Here the steel-wire armour which encircles the cable plays an unwelcome part. Induction is always proportioned to the conductivity of the mass in which it appears; as steel is an excellent conductor, the armour of an ocean cable, close as it is to the copper core, has induced in it a current much stronger, and therefore more retarding, than if the steel wire were absent.

A word now as to the second difficulty in working beneath the sea—that due to the absorbing power of the line itself. An Atlantic cable, like any other extended conductor, is virtually a long, cylindrical Leyden jar, the copper wire forming the inner coat, and its surroundings

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[1] *A Century of Electricity.* Boston, Houghton, Mifflin & Co., 1887.

the outer coat. Before a signal can be received at the distant terminus the wire must first be charged. The effect is somewhat like transmitting a signal through water which fills a rubber tube; first of all the tube is distended, and its compression, or secondary effect, really transmits the impulse. A remedy for this is a condenser formed of alternate sheets of tin-foil and mica, *C*, connected with the battery, *B*, so as to balance the electric charge of the cable wire (Fig. 60). In the first Atlantic line an impulse demanded one-seventh of a second for its journey. This was reduced when Mr. Whitehouse made the capital discovery that the speed of a signal is increased threefold when the wire is alternately connected with the zinc and copper poles of the battery. Sir William Thomson ascertained that these successive pulses are most effective when of proportioned lengths. He accordingly devised an automatic transmitter which draws a duly perforated strip of paper under a metallic spring connected with the cable. To-day 250 to 300 letters are sent per minute instead of 15, as at first.

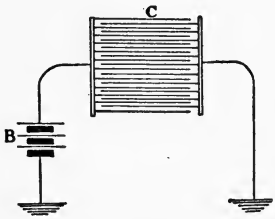

FIG. 60.
Condenser.

In many ways a deep-sea cable exaggerates in an instructive manner the phenomena of telegraphy over long aerial lines. The two ends of a cable may be in regions of widely diverse electrical potential, or pressure, just as the readings of the barometer at these two places may differ much. If a copper wire were allowed to offer itself as a gateless conductor it would equalise these variations of potential with serious injury to itself. Accordingly the rule is adopted of working the cable not directly, as if it were a land line, but indirectly through condensers. As the throb sent through such apparatus is but momentary, the cable is in no risk from the strong currents which would course through it if it were permitted to be an open channel.

A serious error in working the first cables was in supposing that they required strong currents as in land lines of considerable length. The very reverse is the fact. Mr. Charles Bright, in *Submarine Telegraphs*, says:

> Mr. Latimer Clark had the conductor of the 1865 and 1866 lines joined together at the Newfoundland end, thus forming an unbroken length of 3700 miles in circuit. He then placed some sulphuric acid in a very small silver thimble, with a fragment of zinc weighing a grain or two. By this primitive agency he succeeded in conveying signals through twice the breadth of the Atlantic Ocean in little more than a second of time after making contact. The deflections were not of a dubious character, but full and strong, from which it was manifest that an even smaller battery would suffice to produce somewhat similar effects.

At first in operating the Atlantic cable a mirror galvanometer was employed as a receiver. The principle of this receiver has often been illustrated by a mischievous boy as, with a slight and almost imperceptible motion of his hand, he has used a bit of looking-glass to dart a ray of reflected sunlight across a wide street or a large room.

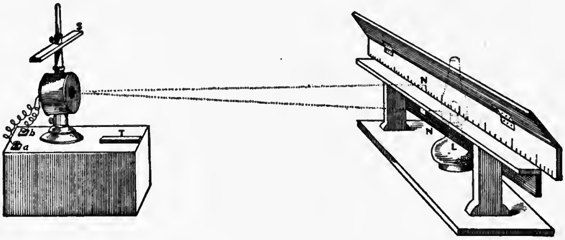

FIG. 61.
Reflecting galvanometer.
L, lamp; *N*, moving spot of light reflected from mirror.

On the same plan, the extremely minute motion of a galvanometer, as it receives the successive pulsations of a message, is magnified by a weightless lever of light so that the words are easily read by an operator (Fig. 61). This beautiful invention comes from the hands of Sir William Thomson, who, more than any other electrician, has made ocean telegraphy an established success.

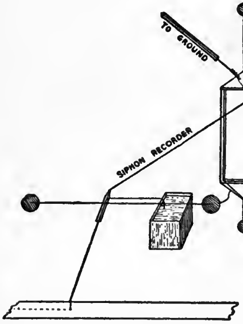

FIG. 62.
Siphon recorder.

In another receiver, also of his design, the siphon recorder, he began by taking advantage of the fact, observed long before by Bose, that a charge of electricity stimulates the flow of a liquid. In its original form the ink-well into which the siphon dipped was insulated and charged to a high voltage by an influence-machine; the ink, powerfully repelled, was spurted from the siphon-point to a moving strip of paper beneath (Fig. 62). It was afterward found better to use a delicate mechanical shaker which throws out the ink in minute drops as the cable current gently sways the siphon back and forth (Fig. 63).

Minute as the current is which suffices for cable telegraphy, it is essential that the metallic circuit be not only unbroken, but unimpaired throughout. No part of his duty has more severely taxed the resources of the electrician than to discover the breaks and leaks in his ocean cables. One of his methods is to pour electricity, as it were, into a broken wire, much as if it were a narrow tube, and estimate the length of the wire (and consequently the distance from shore to the defect or break) by the quantity of current required to fill it.

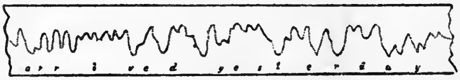

FIG. 63.
Siphon record. "Arrived yesterday."

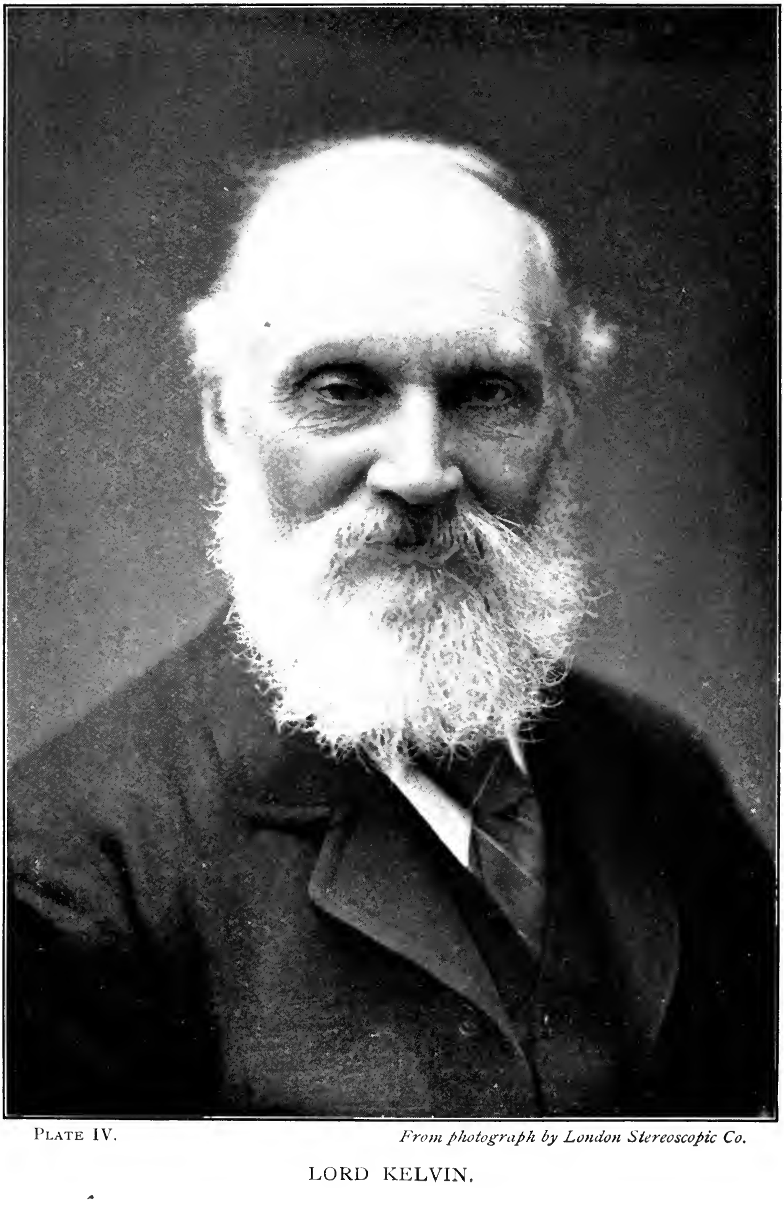

PLATE IV. *From photograph by London Stereoscopic Co.*

LORD KELVIN.

CHAPTER XV

MULTIPLEX TELEGRAPHY

AS long as rays of light were the sole resource of the signaller, all that he did, or could do, was to send a single message at a time. When telegraphy passed from light to electricity as its agent, it became possible to send two, and afterward many, messages over a wire at the same instant. In Chapter XII was mentioned the Gray harmonic method of making a wire carry at the same moment several messages unconfused. We noted also one of the inventions of Mr. P. B. Delany for increasing the capacity of a wire by sending messages at a rate pos-

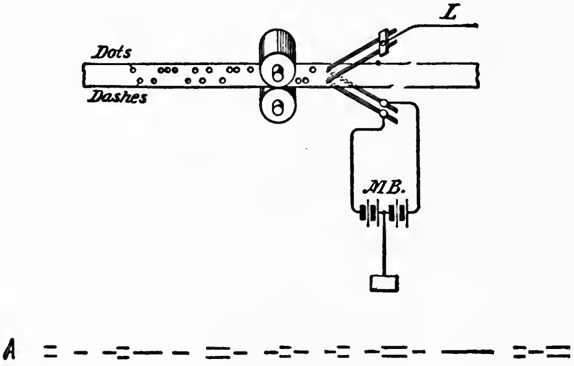

FIG. 64.
Delany perforated message, "telegraphy."

Two Messages Go Together in One Direction.

sible only to fingers of brass and steel. In this system a despatch is first expressed in perforations by a suitable machine. The strip of paper is then rolled between two pairs of wire brushes pressing toward each other above and below the paper (Fig. 64). The top brushes are electrically one, and are connected to the line *L*. The bottom brushes are insulated from each other, one being connected to the positive, the other to the negative, pole of the transmitting battery, *MB*. This battery is connected to the earth at its middle. The symbols *A*, as received, signify "telegraphy," a line by itself meaning a dot, two parallel lines meaning a dash.

The same result, the increased capacity of a line, has been accomplished by various other modes; we shall commence a brief review of them by a glance at the diplex system, by which two messages are sent in the same direction at the same time. First of all, let us note that this feat could be readily accomplished by simple mechanical means. Says Mr. Charles L. Buckingham:

> A long rod might be moved backward and forward along its axis by one operator to ring a gong, while at the same time a second operator could rotate the rod about its axis to move a flag or turn the hand of a dial. Two transmissions could also be effected by the action of water in a single pipe. If a section of the pipe were of glass, a valve placed within it could be made visibly to move to and fro, and by the forward and backward flow thus caused to indicate signals of one message, while signals of a second message could independently and simultaneously be indicated by increased pressure, shown by the height of fluid in a vertical-pressure gauge.[1]

No such schemes as these have ever been practically worked out, simply because they would not be worth while. Better and cheaper modes are available; with electricity as the agent, it becomes both easy and profitable to give a

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[1] *Electricity in Daily Life.* New York, Scribner, 1891.

metallic conductor two distinct impulses. Let us note the means by which one of these impulses is sent forward and received. A current of say 40 volts is caused to flow continuously through the telegraph line; the armature at the receiving end has so strong a spring as to be unmoved by this current as it excites an electromagnet; to overcome the spring's resistance the distant operator must use his key to introduce to the line a current of say 100 additional volts, when the armature at once responds. Now this armature is of common soft iron (see *L*, Fig. 55), as in the ordinary telegraph practice where only one despatch at a time need be sent over a wire; the iron is indifferent to the polarity of the electromagnet which it faces. A face of north polarity in the electromagnet will induce south polarity in the soft iron opposite to it; a face of south polarity in the electromagnet will induce north polarity in the soft iron; in either case there is instant attraction.

Currents may differ in strength; they may also differ in the polarity they create in electromagnets; and here the inventor finds a second opportunity for his skill. Let us observe a telegraphic circuit of the simplest kind, actuated by a cell consisting of a zinc and a copper plate immersed in an acid solution; within its circuit is an electromagnet. At the end of its helix, which is joined to the copper plate, a north pole appears; at the other end, joined to the zinc plate, a negative pole is presented (Fig. 65). If we change the connections of the helix, copper for zinc, and zinc for copper, as we may easily do with a reversing-key, a north pole will appear where we had a south pole, and vice versa. Let us now sketch the application of this principle to diplex telegraphy (Fig. 66). Around the elec-

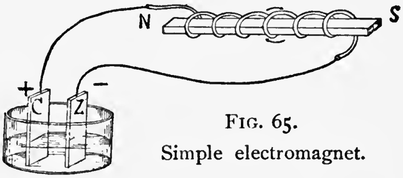

FIG. 65.
Simple electromagnet.

tromagnet *Y* a current is constantly flowing, as in the preceding case, at 40 volts; its effect is to make a south pole of the upper face *BS*. The armature *M* is a permanent magnet always presenting a south pole to *Y*, so that between the two adjacent faces there is only repulsion, without telegraphic effect. But the instant that a reversing-key is depressed *Y* is changed to the condition of *Z*; its upper face becomes a north pole and forthwith attracts the south pole of *M*, delivering a signal. Thus an operator who sends no current whatever into a line, but simply reverses the direction of the current already there, can send a distinct message of his own. The first operator whom we described meanwhile transmits his message solely by increasing the strength of the line current, regardless of the polarity which that current may confer upon the working face of the distant electromagnet at the receiving-station. Without the slightest confusion, the two despatches take their way together over the same wire.

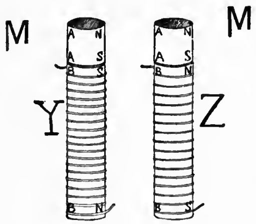

FIG. 66.

Signalling by reversing polarity. In both cases *AN* is a north pole, *AS* a south pole.

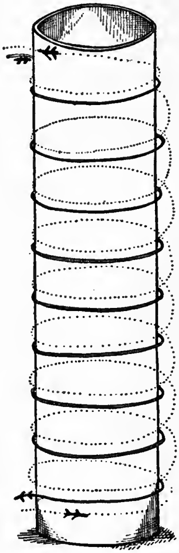

FIG. 67.

Double-wound electromagnet.

As a rule in telegraphic practice it is preferable that the double capacity of a wire should be such as to permit messages to be sent from both terminals at the same time, rather than that two despatches should proceed in company from one terminal. Accordingly, we have duplex systems which perform this feat, and incidentally exhibit the divisibility which electricity alone of all phases of energy offers the inventor in perfection. For brevity's sake but one of these plans will be described. Its success depends on departing in a new way from the simplicity of the common electromagnet. That device has a single coil of wire through which a current invariably excites the core to magnetism. Now if the core is wound with two equal and separate coils, as shown in the dotted and the solid lines (Fig. 67), two equal and contrary currents of electricity sent through their wires will neutralise each other as they course around the iron, and hence will leave it unmagnetised.

Two Messages Go Together in Opposite Directions.

Such a contrivance is the essential feature of an important form of duplex telegraph (Fig. 68). *A* and *B* are two stations, *P* and *P'* are their receiving-instruments, and *K* and *K'* their transmitting-keys. Let us imagine an operator at *A* depressing his key. As he does so his battery current is divided in halves; one half goes into the line running to *B*; the other half enters a short line, *R*, of equal resistance —which may be a few feet of fine German silver. *A*'s local electromagnet *P* is double wound (Fig. 67), and receives into its two coils both currents; as they are equal and opposed the soft iron core is unmagnetised. But at the distant station *B* the receiving-electromagnet *P'*, as

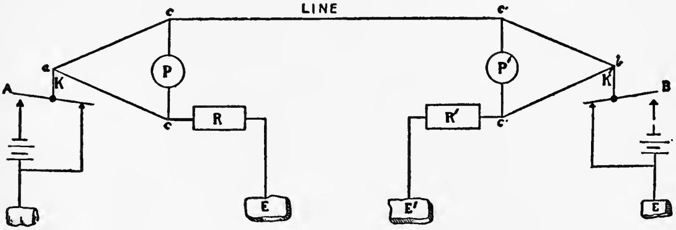

FIG. 68.
Duplex telegraph.

it takes in one-half of the whole current of the battery at *A*, instantly attracts its armature and delivers its signals. All this is true if we consider *B* as the sending and *A* as the receiving station. When the sending-key *K′* is depressed it does not affect the local electromagnet, but the distant instrument at *A* utters a click. By this ingenious balancing of currents it is thus feasible to send two messages simultaneously in opposite directions (Fig. 68).[1]

The duplex telegraph in its original forms suffered from a serious defect. A telegraph-wire retains part of each electric impulse as an electrostatic charge. This charge is not neutralised, as it should be, on an artificial line of small dimensions from sheer insufficiency of surface. In 1872 Joseph B. Stearns of Boston remedied the difficulty by intro-

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[1] A hydraulic analogy of the process is due to Professor T. C. Mendenhall, and appears in his *Century of Electricity*: "Suppose that two persons living in a city supplied with a system of water-works desire to establish telegraphic communication with each other by means of water. Connection between the two points is made by means of a small pipe of iron or other suitable material, into which water from either end can be forced by opening a stop-cock. Some device will be needed to show the passage of the current, and this might be a small inclosed water-wheel, with a suitable index, which is made to turn by the flow of water around it. The essential features of such an arrangement are shown in the diagram [Fig. 69]. The two stations are identical. The stream of water, before entering the box containing the wheel, is divided into two parts, one of which flows around the wheel in one direction and thence into the 'line.' The other passes round the wheel in the opposite direction, and is emptied through a narrow or crooked pipe. Water is admitted by turning the stop-cock *a* or *b*, which differs from the ordinary gas- or water-cock in that an additional opening is provided; so that when the cock is closed, as *a* is represented, thus obstructing the passage from the street main, water from above, after having passed the wheel, can find an easy exit through the end of the cock to the waste, along with that from the narrow pipe *a*, already referred to. The latter, by being thin and crooked, offers as much resistance to the passage of the water as does the whole line, with the wheel and stop-cock at the distant end. This corresponds to the 'artificial line'

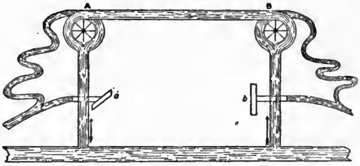

Fig. 69.
Hydraulic model, duplex telegraphy.

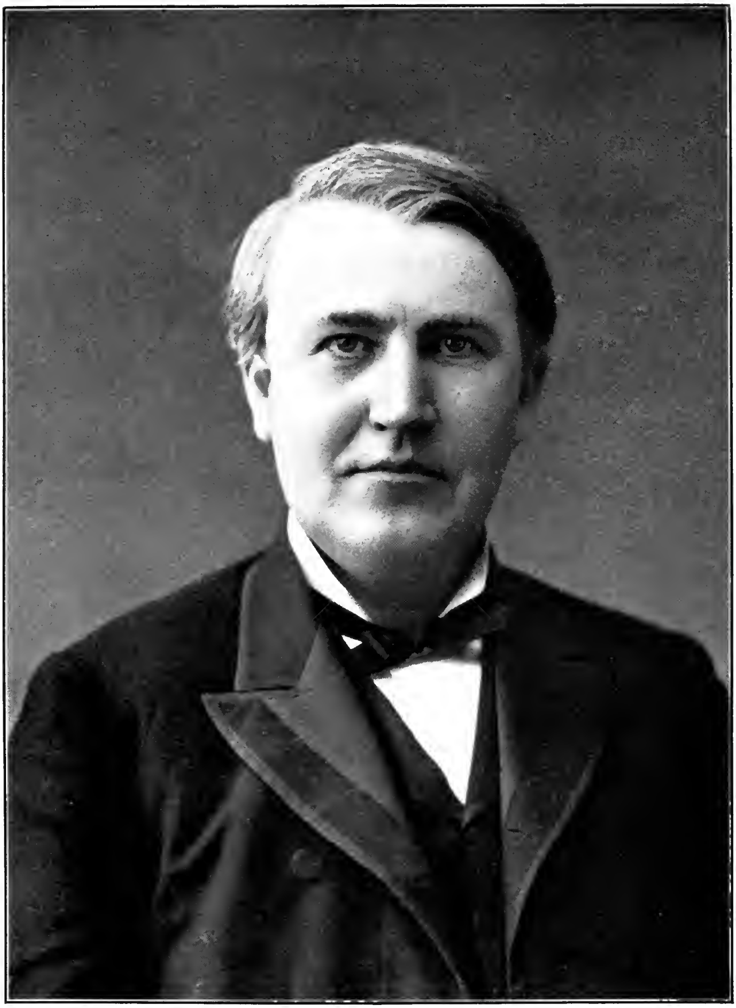

PLATE V. *Copyright by J. W. White & Co.*

THOMAS ALVA EDISON.

ducing condensers as already described in Chapter XIV (Fig. 60). He thus perfectly balanced the electrostatic charge of the line, and duplex telegraphy at once became a commercial success for both land and ocean systems.

Four and More Simultaneous Messages.

By combining the diplex and duplex systems, Mr. Edison, in 1874, constructed the quadruplex, which permits four messages to proceed along a wire at the same time, two from each end.[1]

Adopting a totally different principle, Mr. P. B. Delany has brought to practical success a synchronous telegraph which had engaged the attention of other inventors for many years. An ex-

in the duplex electrical telegraph. The water-wheel, with the divided current flowing about it, is analogous to the 'differential relay'; and the stop-cock to the 'key,' which in one position allows the passage of the current, and in the other affords free egress of the current from the other station to the 'ground.' The water-pressure in the street main plays the part of the electromotive force in the batteries of the electrical system. The operation of the whole as a duplex telegraph will need little explanation. The operator at *A* transmits a signal by opening stop-cock *a*. Water rushes in from the main; and, since the resistances offered by the two paths are equal, it divides equally in flowing around the wheel. Equal currents being thus applied to the opposite sides of the latter, it remains at rest. Half the current, however, passes through the line, and reaching the receiving-instrument at *B*, passes around the wheel there on one side and out through the stop-cock *b*; or, if a small part passes through the artificial line (and this will always be the case), it goes in such a way as to aid, and not to oppose, the movement of the wheel. Thus a signal will be received at *B* which will be interpreted as a dot or a dash according as the time of motion is short or long. Of course, the transmission of a signal from *B* to *A* is accomplished in precisely the same way. If both stop-cocks are opened at the same moment, it will easily be seen that the two equal opposing currents in the line will prevent any actual flow, and at each end flow will take place only into the artificial line, and signals will be recorded at both. It is also clear that if the operator at *B*, wishing to send a dash when only a dot is to be transmitted from *A*, shall continue to hold his key open after the other is closed, the balance will be at once established at *B*, the wheel will cease to move, and a dot will be recorded; while the current from *B*, now flowing through the line, will maintain the motion at *A* until a dash is registered there."

[1] This and much similar apparatus is described and illustrated in many standard works, among which may be named *American Telegraphy*, by William Maver, Jr. New York, William Maver & Co.

pert telegrapher can make at the most but ten pulsations per second with his key; a good aerial line of moderate length can convey forty to fifty times as many. For simplicity's sake let us suppose that the Delany system employs four operators at each end of a wire, and that the four we shall observe at one terminal are all sending messages. The instrument of each is electrically connected by a trailer to a quadrant of a metallic wheel, *A*, each instrument affecting no other than its own particular and insulated quadrant. The wheel rotates twenty times a second, let us say, so that even while a single dot is being formed by an operator the wheel has spun round a full circle (Fig. 70). At the receiving-station is a similar wheel, *B*, which is rotated at precisely the same rate as its fellow, *A*. When a key at *A* is on quadrant *a*1, a trailer at *B* will send a current through *b*1 to a telegraphic sounder, and so with the other three quadrants. In effect the wire has been divided into four parts, and four independent messages take their way through it at the same time. Indeed, it is easy to employ for each operator, not a quadrant, but an arc of 30° in the circle traversed by the wheel, so that twelve despatches instead of four may course over the wire simultaneously. Mr. Delany's success in this ingenious telegraph consists in the use of correcting impulses, sent automatically into the line, so as to keep the trailers in strict step one with the other. His system is extensively adopted in Great Britain.

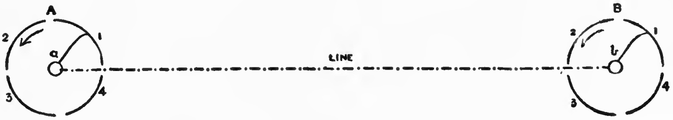

FIG. 70.
Delany synchronous telegraph.

CHAPTER XVI

WIRELESS TELEGRAPHY

THUS far we have directed our attention to modes of telegraphy which depend upon conduction, upon the conveyance of a current by an unbroken metallic wire suspended or laid between two stations.

What may Follow upon Induction.

In a series of experiments interesting enough, but barren of utility, the water of a canal, river, or bay has often served as a conductor for the telegraph. Among the electricians who have thus impressed water into their service was Professor Morse. In 1842 he sent a few signals across the channel from Castle Garden, New York, to Governor's Island, a distance of a mile. With much better results, he sent messages, later in the same year, from one side of the canal at Washington to the other, a distance of eighty feet, employing large copper plates at each terminal. The enormous current required to overcome the resistance of water has barred this method from practical adoption.

We pass, therefore, to electrical communication as effected by induction—the influence which one conductor exerts on another through an intervening insulator. At the outset we shall do well to bear in mind that magnetic phenomena, which are so closely akin to electrical, are always inductive. To observe a common example of magnetic induction, we have only to move a horseshoe magnet in the vicinity of a compass needle, which will instantly sway about as if blown hither and thither by a sharp draught of air. This action takes place if a slate, a pane of glass, or a shingle is interposed between the needle and its perturber. There is no known insulator for magnetism, and as induction of this kind exerts itself perceptibly for many yards when large masses of iron are polarised, the derangement of compasses at sea from moving iron objects aboard ship, or from ferric ores underlying a sea-coast, is a constant peril to the mariner.

Electrical conductors behave much like magnetic masses. A current conveyed by a conductor induces a counter-current in all surrounding bodies, and in a degree proportioned to their conductive power. This effect is, of course, greatest upon the bodies nearest at hand, and we have already remarked its serious retarding effect in ocean telegraphy. When the original current is of high intensity, it can induce a perceptible current in another wire at a distance of several miles. In 1842 Henry remarked that electric waves had this quality, but in that early day of electrical interpretation the full significance of the fact eluded him. In the top room of his house he produced a spark an inch long, which induced currents in wires stretched in his cellar, through two thick floors and two rooms which came between. Induction of this sort causes the annoyance, familiar in single telephonic circuits, of being obliged to overhear other subscribers, whose wires are often far away from our own.

Telegraphy to a Moving Train.

The first practical use of induced currents in telegraphy was when Mr. Edison, in 1885, enabled the trains on a line of the Staten Island Railroad to be kept in constant communication with a telegraphic wire, suspended in the ordinary way beside the track. The roof of a car was of insulated metal, and every tap of an operator's key within the walls electrified the roof just long enough to induce a brief pulse through the telegraphic circuit. In sending a message to the car this wire was, moment by moment, electrified, inducing a response first in the car roof, and next in the "sounder" beneath it. This remarkable apparatus, afterward used on the Lehigh Valley Railroad, was discontinued from lack of commercial support, although it would seem to be advantageous to maintain such a service on other than commercial grounds. In case of chance obstructions on the track, or other peril, to be able to communicate at any moment with a train as it speeds along might mean safety instead of disaster. The chief item in the cost of this system is the large outlay for a special telegraphic wire.

The Preece Induction Method.

The next electrician to employ induced currents in telegraphy was Mr. (now Sir) William H. Preece, the engineer then at the head of the British telegraph system. Let one example of his work be cited. In 1896 a cable was laid between Lavernock, near Cardiff, on the Bristol Channel, and Flat Holme, an island three and a third miles off. As the channel at this point is a much-frequented route and anchor-ground, the cable was broken again and again. As a substitute for it Mr. Preece, in 1898, strung wires along the opposite shores, and found that an electric pulse sent through one wire instantly made itself heard in a telephone connected with the other. It would seem that in this etheric form of telegraphy the two opposite lines of wire must be each as long as the distance which separates them; therefore, to communicate across the English Channel from Dover to Calais would require a line along each coast at least twenty miles in length. Where such lines exist for ordinary telegraphy, they might easily lend themselves to the Preece system of signalling in case a submarine cable were to part.

Marconi, adopting electrostatic instead of electromagnetic waves, has won striking results. Let us note the chief of his forerunners, as they prepared the way for him. In 1864 Maxwell observed that electricity and light have the same velocity, 186,400 miles a second, and he formulated the theory that electricity propagates itself in waves which differ from those of light only in being longer. This was proved to be true by Hertz, in 1888, who showed that where alternating currents of very high frequency were set up in an open circuit, the energy might be conveyed entirely away from the circuit into the surrounding space as electric waves. His detector was a nearly closed circle of wire, the ends being soldered to metal balls almost in contact. With this simple apparatus he demonstrated that electric waves move with the speed of light, and that they can be reflected and refracted precisely as if they formed a visible beam At a certain intensity of strain the air insulation broke down, and the air became a conductor. This phenomenon of passing quite suddenly from a non-conductive to a conductive state is, as we shall duly see, also to be noted when air or other gases are exposed to the X ray.

The Marconi System.

Now for the effect of electric waves such as Hertz produced, when they impinge upon substances reduced to powder or filings. Conductors, such as the metals, are of inestimable service to the electrician; of equal value are non-conductors, such as glass and gutta-percha, as they strictly fence in an electric stream. A third and remarkable vista opens to experiment when it deals with substances which, in their normal state, are non-conductive, but which, agitated by an electric wave, instantly become conductive in a high degree. As long ago as 1866 Mr. S. A. Varley noticed that black lead, reduced to a loose dust, effectually intercepted a current from fifty Daniell cells, although the battery poles were very near each other. When he increased the electric tension four- to sixfold, the black-lead particles at once compacted themselves so as to form a bridge of excellent conductivity. On this principle he invented a lightning-protector for electrical instruments, the incoming flash causing a tiny heap of carbon dust to provide it with a path through which it could safely pass to the earth. Professor Temistocle Calzecchi Onesti of Fermo, in 1885, in an independent series of researches, discovered that a mass of powdered copper is a non-conductor until an electric wave beats upon it; then, in an instant, the mass resolves itself into a conductor almost as efficient as if it were a stout, unbroken wire. Professor Edouard Branly of Paris, in 1891, on this principle devised a coherer, which passed from resistance to invitation when subjected to an electric impulse from afar. He enhanced the value of his device by the vital discovery that the conductivity bestowed upon filings by electric discharges could be destroyed by simply shaking or tapping them apart.

In a homely way the principle of the coherer is often illustrated in ordinary telegraphic practice. An operator notices that his instrument is not working well, and he suspects that at some point in his circuit there is a defective contact. A little dirt, or oxide, or dampness, has come in between two metallic surfaces; to be sure, they still touch each other, but not in the firm and perfect way demanded for his work. Accordingly he sends a powerful current abruptly into the line, which clears its path thoroughly, brushes aside dirt, oxide, or moisture, and the circuit once more is as it should be. In all likelihood, the coherer is acted upon in the same way. Among the physicists who studied it in its original form was Dr. Oliver J. Lodge. He improved it so much that, in 1894, at the Royal Institution in London, he was able to show it as an electric eye that registered the impact of invisible rays at a distance of more than forty yards. He made bold to say that this distance might be raised to half a mile.

As early as 1879 Professor D. E. Hughes began a series of experiments in wireless telegraphy, on much the lines which in other hands have now reached commercial as well as scientific success. Professor Hughes was the inventor of the microphone, and that instrument, he declared, affords an unrivalled means of receiving wireless messages, since it requires no tapping to restore its non-conductivity. In his researches this investigator was convinced that his signals were propagated, not by electromagnetic induction, but by aerial electric waves spreading out from an electric spark. Early in 1880 he showed his apparatus to Professor Stokes, who observed its operation carefully. His dictum was that he saw nothing which could not be explained by known electromagnetic effects. This erroneous judgment so discouraged Professor Hughes that he desisted from following up his experiments, and thus, in all probability, the birth of the wireless telegraph was for several years delayed.[1]

The coherer, as improved by Marconi, is a glass tube about $1\frac{1}{2}$ inches long and about $\frac{1}{12}$ of an inch in internal diameter. The electrodes are inserted in this tube so as almost to touch; between them is about $\frac{1}{30}$ of an inch filled with a pinch of the responsive mixture which forms the pivot of the whole contrivance. This mixture is 90 per cent. nickel filings, 10 per cent. hard silver filings, and a mere trace of mercury; the tube is exhausted of air to within $\frac{1}{10000}$ part (Fig. 71). How does this trifle of metallic dust manage loudly

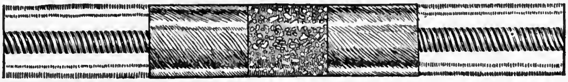

FIG. 71.
Marconi coherer, enlarged view.

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[1] *History of the Wireless Telegraph*, by J. J. Fahie. Edinburgh and London, William Blackwood & Sons; New York, Dodd, Mead & Co., 1899. This work is full of interesting detail, well illustrated.

to utter its signals through a telegraphic sounder, or forcibly indent them upon a moving strip of paper? Not directly, but indirectly, as the very last refinement of initiation. Let us glance at Fig. 72, which shows in the simplest outlines a Marconi apparatus. *K* is a telegraph-key, which, at the transmitting-station, sends a current from *B*, a battery and induction coil, to *S* and *T*, two brass spheres about three inches in diameter, and mounted a small distance apart. The spark which, during the depression of the key *K*, passes between the spheres, sends forth the electric waves which bear the signal afar. *C* is the coherer at the receiving-station, mounted with metallic wings, *W* and *W*, to catch the electric waves; the coherer at each end is joined to the metallic circuit of the voltaic cell *M*. In this circuit or chain, the coherer, when unexcited, forms a link which obstructs the flow of a current eager to leap across. The instant that an electric wave from the sending-station impinges upon the coherer it becomes conductive; the current instantly glides through it, and at the same time a current, by means of a relay, is sent through the powerful voltaic battery *N*, so as to announce the signal through an ordinary telegraphic receiver.

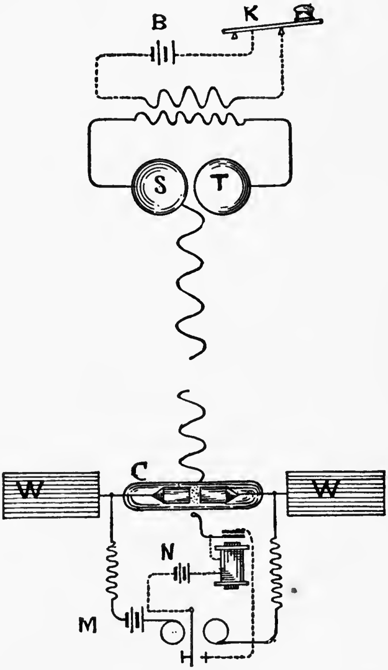

FIG. 72.
Marconi telegraph apparatus.

An electric impulse, almost too attenuated for computation, is here able to effect such a change in a pinch of dust that it becomes a free avenue instead of a barricade. Through that avenue a powerful blow from a local store of energy makes itself heard and felt. No device of the trigger class is comparable with this in delicacy. An instant after a signal has taken its way through the coherer a small hammer strikes the tiny tube, jarring its particles asunder, so that they resume their normal state of high resistance. We may well be astonished at the sensitiveness of the metallic filings to an electric wave originating many miles away, but let us remember how clearly the eye can see a bright lamp at the same distance as it sheds a sister beam. Thus far no substance has been discovered with a mechanical responsiveness to so feeble a ray of light; in the world of nature and art the coherer stands alone. The electric waves employed by Marconi are about four feet long, or have a frequency of about 250,000,000 per second. Such undulations pass readily through brick or stone walls, through common roofs and floors—indeed, through all substances which are non-conductive to electric waves of ordinary length. Were the energy of a Marconi sending-instrument applied to an arc-lamp, it would generate a beam of a thousand candle-power. We have thus a means of comparing the sensitiveness of the retina to light with the responsiveness of the Marconi coherer to electric waves, after both radiations have undergone a journey of miles.

An essential feature of this method of etheric telegraphy, due to Marconi himself, is the suspension of a perpendicular wire at each terminus, its length twenty feet for stations a mile apart, forty feet for four miles, and so on, the telegraphic distance increasing as the square of the length of suspended wire. In the Kingstown regatta, July, 1898, Marconi sent from a yacht under full steam a report to the shore without the loss of a moment from start to finish.

This feat was repeated during the protracted contest between the *Columbia* and the *Shamrock* yachts in New York Bay, October, 1899. On March 28, 1899, Marconi signals put Wimereux, two miles north of Boulogne, in communication with the South Foreland Lighthouse, thirty-two miles off.[1] In August, 1899, during the manœuvres of the British navy, similar messages were sent as far as eighty miles. It was clearly demonstrated that a new power had been placed in the hands of a naval commander. "A touch on a button in a flagship is all that is now needed to initiate every tactical evolution in a fleet, and insure an almost automatic precision in the resulting movements of the ships. The flashing lantern is superseded at night, flags and the semaphore by day, or, if these are retained, it is for services purely auxiliary. The hideous and bewildering shrieks of the steam-siren need no longer be heard in a fog, and the uncertain system of gun signals will soon become a thing of the past." The interest of the naval and military strategist in the Marconi apparatus extends far beyond its communication of intelligence. Any

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[1] The value of wireless telegraphy in relation to disasters at sea was proved in a remarkable way yesterday morning. While the Channel was enveloped in a dense fog, which had lasted throughout the greater part of the night, the East Goodwin Light-ship had a very narrow escape from sinking at her moorings by being run into by the steamship *R. F. Matthews*, 1964 tons gross burden, of London, outward bound from the Thames. The East Goodwin Light-ship is one of four such vessels marking the Goodwin Sands, and, curiously enough, it happens to be the one ship which has been fitted with Signor Marconi's installation for wireless telegraphy. The vessel was moored about twelve miles to the northeast of the South Foreland Lighthouse (where there is another wireless-telegraphy installation), and she is about ten miles from the shore, being directly opposite Deal. The information regarding the collision was at once communicated by wireless telegraphy from the disabled light-ship to the South Foreland Lighthouse, where Mr. Bullock, assistant to Signor Marconi, received the following message: "We have just been run into by the steamer *R. F. Matthews* of London. Steamship is standing by us. Our bows very badly damaged." Mr. Bullock immediately forwarded this information to the Trinity House authorities at Ramsgate. — *Times*, April 29, 1899.

electrical appliance whatever may be set in motion by the same wave that actuates a telegraphic sounder. A fuse may be ignited, or a motor started and directed, by apparatus connected with the coherer, for all its minuteness. Mr. Walter Jamieson and Mr. John Trotter have devised means for the direction of torpedoes by ether waves, such as those set at work in the wireless telegraph. Two rods projecting above the surface of the water receive the waves, and are in circuit with a coherer and a relay. At the will of the distant operator a solenoid draws in an iron core either to the right or to the left, moving the helm accordingly.

As the news of the success of the Marconi telegraph made its way to the London Stock Exchange there was a fall in the shares of cable companies. The fear of rivalry from the new invention was baseless. As but 15 words a minute are transmissible by the Marconi system, it evidently does not compete with a cable, such as that between France and England, which can transmit 2500 words a minute without difficulty. The Marconi telegraph comes less as a competitor to old systems than as a mode of communication which creates a field of its own. We have seen what it may accomplish in war, far outdoing any feat possible to any other apparatus, acoustic, luminous, or electrical. In quite as striking fashion does it break new ground in the service of commerce and trade. It enables lighthouses continually to spell their names, so that receivers aboard ship may give the steersmen their bearings even in storm and fog. In the crowded condition of the steamship "lanes" which cross the Atlantic, a priceless security against collision is afforded the man at the helm. On November 15, 1899, Marconi telegraphed from the American liner *St. Paul* to the Needles, sixty-six nautical miles away. In many cases the telegraphic business to an island is too small to warrant the laying of a cable; hence we find that Trinidad and Tobago are to be joined by the wireless system, as also five islands of the Hawaiian group, eight to sixty-one miles apart.

A weak point in the first Marconi apparatus was that anybody within the working radius of the sending-instrument could read its message. To modify this objection secret codes were at times employed, as in commerce and diplomacy. A complete deliverance from this difficulty is promised in attuning a transmitter and a receiver to the same note, so that one receiver, and no other, shall respond to a particular frequency of impulses. The experiments which indicate success in this vital particular have been conducted by Professor Lodge.

When electricians, twenty years ago, committed energy to a wire and thus enabled it to go round a corner, they felt that they had done well. The Hertz waves sent abroad by Marconi ask no wire, as they find their way, not round a corner, but through a corner. On May 1, 1899, a party of French officers on board the *Ibis* at Sangatte, near Calais, spoke to Wimereux by means of a Marconi apparatus, with Cape Grisnez, a lofty promontory, intervening. In ascertaining how much the earth and the sea may obstruct the waves of Hertz there is a broad and fruitful field for investigation. "It may be," says Professor John Trowbridge, "that such long electrical waves roll around the surface of such obstructions very much as waves of sound and of water would do."

It is singular how discoveries sometimes arrive abreast of each other so as to render mutual aid, or supply a pressing want almost as soon as it is felt. The coherer in its present form is actuated by waves of comparatively low frequency, which rise from zero to full height in extremely brief periods, and are separated by periods de-

FIG. 73.
Discontinuous electric waves.

cidedly longer (Fig. 73). What is needed is a plan by which the waves may flow either continuously or so near together that they may lend themselves to attuning. Dr. Wehnelt, by an extraordinary discovery, may, in all likelihood, provide the lacking device in the form of his interrupter, which breaks an electric circuit as often as two thousand times a second. The means for this amazing performance are simplicity itself (Fig. 74). A jar, *a*, containing a solution of sulphuric acid has two electrodes immersed in it; one of them is a lead plate of large surface, *b*; the other is a small platinum wire which protrudes from a glass tube, *d*. A current passing through the cell between the two metals at *c* is interrupted, in ordinary cases five hundred times a second, and in extreme cases four times as often, by bubbles of gas given off from the wire instant by instant.[1]

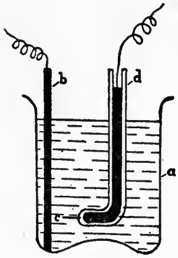

FIG. 74.
Wehnelt interrupter.

The Grasp of Electric Telegraphy.

The adoption of electricity in its diverse phases, in lieu of visible signals as a communicator of intelligence, is one of the distinctive leaps of human progress. A hundred years ago the Chappé telegraph could transmit per minute but three signals between one station and another, for a distance of ten miles. To-day a single wire joining Paris and Toulon, 475 miles apart, can easily bear 6000 signals a minute, and this in perfect independence of daylight or good weather. Because a metallic wire can thus carry many more messages than one opera-

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[1] This curious contrivance affords a ready means of producing the sparks needed for gas-engines; it is the simplest means of converting a continuous into an alternating current, and hence offers notable service to jewellers and other artisans who wish a welding current of small volume. In radiography it has reduced the time of exposure by as much as three fourths, besides giving remarkably steady images on the fluorescent screen.—*Electrical World and Engineer*, May 20, 1899.

tor can transmit, we find in the field a wide variety of multiple systems of telegraphy, none of them possible before the electric age. In the harmonic method the wire becomes in effect a medium for the conveyance of musical tones, each of them unheard except through a sympathetic reed. In a second plan the dual polarity of an electric current enables it to carry two messages as clearly as one. In yet another mode a response is given only to an impulse of more than ordinary force, as if the instrument slept under any knock but a heavy one. By another and totally different scheme the current is so subdivided that a dozen despatches may be borne abreast, this by the synchronous rotation at high speed of two wheels hundreds of miles apart. As the latest and perhaps the last term in the series, we have a telegraph which dispenses with connecting wires altogether, and takes its way like a pencil of light through the ether of space. All these methods, diverse as they are, have one limitation—their messages must take the form of an arbitrary code of signals. "A" must be a short tap and a long one, and so on throughout the alphabet. It remained for the telephone to banish this one restriction, and so marry sound and electricity that a metallic thread carries electrical pulses which are virtually those of every tone and cadence of the human voice.

CHAPTER XVII

THE TELEPHONE

IN the history of invention it has often appeared that a feat has been really much more simple than it seemed to be at first view. More than one good engineer at the inception of railroading thought that the rails and the wheels must be toothed if they were to be trusted around sharp curves and up steep gradients. And so it was with the problem of telephony. Its pioneers saw looming between the domain of electricity and the world of sound nothing short of a mountain of difficulty. As they ascended its heights they beheld at its very base a straight and easy mode of translating the pulses of the voice into equal throbs of electricity.

From Complexity to Simplicity.

The first explorer here was Dr. Page. In 1837 he noticed that a musical sound issued from the core of an electromagnet whenever contact was made or broken between its coil and a battery.[1] His experiments were repeated and extended by many inquirers at home and abroad, who saw a prospect of thus transmitting music by telegraph not less easily than the dots and dashes of a common message. Of these men the most notable was Johann Philipp Reis of Friedrichsdorf, in Germany. In

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[1] *American Journal of Science.* First series, Vol. XXXII, p. 369, and Vol. XXXIII, p. 354.

1861 he devised an electrical instrument which transmitted not only music but also vowel sounds, although not in a sufficiently clear and reliable way to be accounted a success. The goal which Reis so narrowly missed took on a new accessibility when Helmholtz completed his masterly analysis of vowel sounds. With nothing more than a hollow sphere he resolved *a*, *e*, *i*, *o*, and *u* into their constituent musical elements, much as Newton with a simple prism had divided a beam of white light into its component coloured rays. Armed with a series of tuning-forks, actuated by electricity, he proceeded to prove his analysis true. Uniting a series of fundamental tones, he reproduced the vowels with unmistakable clearness.

The possibility that articulate speech might be committed to an electric wire and recovered from it now plainly pictured itself in the imagination of three great inventors—Elisha Gray, Alexander Graham Bell, and Thomas Alva Edison. Inasmuch as Bell, by his fortunate choice of an undulatory current, has given the world the best instrument, it may be sufficient to confine attention to the steps by which he arrived at his victory. The original impulse in his work came from his distinguished father, Professor Alexander Melville Bell, whose life has been devoted to a critical study of articulate speech, and who has invented for articulate sounds an alphabet of forty-four symbols, which is known as "visible speech." This veteran of science, writing from his residence in Washington, gives us, under the date of November 14, 1899, this noteworthy account of the incitements which ended in the telephone: "In the boyhood of my three sons I took them to see the speaking-machine constructed by Herr Faber, and we were all greatly interested in it professionally. To test their theoretical knowledge, and their mechanical ingenuity, I offered a prize to the one who should produce the best results in imitation of speech by mechanical means. All, of course, set to work, but nothing of startling novelty was devised. The scheme of my second son, A. G. Bell, was, however, the best. This contest—as well as the whole course of the boys' education—directed their minds to the subject, until the sole survivor of the lads came to the conclusion that imitative mechanism might be dispensed with, and merely the *vibrations* of speech be transmitted to an electric wire. This was entirely his own idea. He illustrated it to me by diagrams, and sketched out the whole plan of central-office communication, long before anything had been done for the practical realisation of the idea. I can claim nothing in the telephone but the impulse which led to the invention."

Soon after the telephone had proved itself to be thoroughly successful, its inventor was invited to deliver a lecture, on October 31, 1877, before the Society of Telegraph Engineers, in London. He said:

> When we sing into a piano, certain of the strings of the instrument are set in vibration sympathetically by the action of the voice with different degrees of amplitude, and a sound, which is an approximation to the vowel uttered, is produced from the piano. Theory shows that, had a piano a very much larger number of strings to the octave, the vowel sounds would be perfectly reproduced. My idea was to use a harp-like apparatus, and throw certain of the rods into vibration by sounds of different amplitudes. At the other end of the circuit the corresponding rods of a second harp would vibrate with their proper relations of force, and the timbre of the sound would be reproduced. The expense of constructing the apparatus deterred me from making the attempt, and I sought to simplify the apparatus before having it made.[1]

As the result of a long series of experiments, he discovered that the complexity of the diverse rods of a harp was quite unnecessary; a piece of clock-spring, about the size and shape of his thumb-nail, glued to the centre of a membrane of gold-beaters' skin, was adequate to receiving every

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[1] *The Speaking Telephone*, by G. B. Prescott. New York, Appleton, 1878.

tone of the voice, while a second apparatus of identical simplicity repeated the words at the distant end of a wire. It took a long and roundabout search to find that the best path for the electric transmission of speech is the short and direct course of talking to one simple disc and listening at another.

A Carbon Button Reinforces Sound.

When Professor Bell exhibited his telephone at Philadelphia, in 1876, nothing seemed less probable than that he had entered upon a serious rivalry with the telegraph. The tones of the little disc were lisping and feeble; it was sometimes hard to convince its auditors that they were hearing anything else than sounds which had set up no partnership with electricity, and were pulsing through the wire precisely as they might through the string of that common acoustic toy, the lovers' telegraph (Fig. 75). The week-day noises of the Exhibition building so completely drowned its tones that only with Sabbath quiet were its messages distinct to the ear. At first Professor Bell used the same instrument in speaking and in listening. To-day the instrument into which one speaks, the transmitter, differs in essential details from the receiver at which one listens. The telephone as it left the hands of its inventor was nearly perfect in its task of reproducing speech from minute currents as they arrived from a distance. For the work of transforming the energy of the voice into electric pulses the transmitter was imperfect, and could not have been a commercial success but for its improvement by Hughes, Blake, and Edison. All three added an element indispensable in other branches of the electric art, namely,

FIG. 75.

Lovers' telegraph. Two bits of tubing have each an end closed by a membrane; between the centres of the membranes a string conveys speech for several hundred feet.

carbon, which here displays a property of the utmost value.

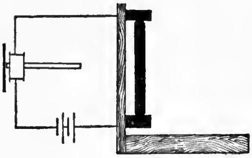

FIG. 76.
Microphone.

The electrical resistance of a small mass of carbon responds in the most sensitive way to the slightest variation in the mechanical pressure to which it may be exposed (Fig. 76). Mount a small upright stick of carbon on pivots, which it lightly touches, send an electric current through it, and a feather stroke upon the carbon so lifts and lowers its resistance that in a connected telephone one hears a succession of loud raps. It must not be supposed that these raps are the magnified sounds of the feather as it moves along. They would be heard just as distinctly if the feather and the carbon were inclosed in a vacuum and so cushioned as in themselves to be perfectly silent. It is the changing resistance of the stick that gives rise to the sounds, a phenomenon which reappears, as we shall presently observe, in the photophone. In the improved forms of telephone a carbon button is placed in a local electric circuit, and under the slight variations of pressure exerted by the sound-waves of speech this button undergoes wide fluctuations in its electric resistance, so that electric pulses much intensified are sent into the line. In its original form the telephone did little else than utter an uneven whisper, and Professor Bell intended to use it solely in lecture-room illustrations. A sphere of commercial acceptance as wide as the world followed the moment that the carbon microphone brought a muffled lisp to full and clear audibility.

Two magnetic telephones of rough-and-ready manufacture, with a hundred feet of wire, may be made wholesale for a dollar; yet in their simplicity of construction, united to complexity of working, they are among the most remarkable creations of the age. Fig. 77 shows the anatomy of such instruments. *D* is the thin iron disc against which one speaks as it all but touches *P*, the pole of the permanent steel magnet contained in the case *M*. As the disc is urged and withdrawn by the pulses of the voice it comes into fluctuating degrees of approach to *P*; this causes the magnetism of *P* to vary in sympathy. Whenever a magnet inclosed in a coil of wire, *C*, thus varies in strength, minute currents of electricity are created in the coil; such currents accordingly pass to the line-wires, *W*, *W*. The electric undulations arrive at a receiving-instrument which, for simplicity's sake, we shall assume to be identical with the sending-apparatus. They circulate round a steel magnet whose attractive power upon a disc they modify from instant to instant. Because the receiving-disc in this indirect manner thus vibrates in sympathy with the transmitting-disc, the speaker's words arrive with characteristic though weakened tones at *B* as sent from *A* (Fig. 78). Surely there is nothing in electric art more marvellous than this persistence of infinitesimal waves in all their sinuosities, through repeated transfer and transformation. That matter may be impressed by forces next to nothing in quantity, and that these impressions may be transmitted for miles and recov-

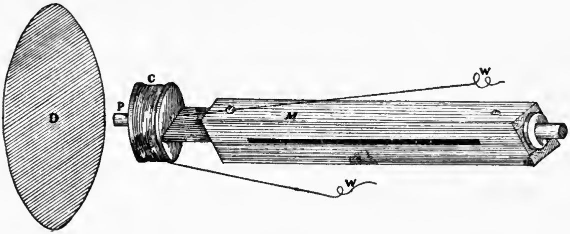

FIG. 77.
Telephone dissected.

FIG. 78.
Telephonic circuit.

ered with no loss of character, are among the most wonderful facts of nature, and as serviceable as they are wonderful.

Simpler than the Telegraph.

The telephone is not simply a rival to the telegraph in many fields: it cultivates a vast domain of its own. The telegraph suffers from a serious restriction in that it speaks a language not understood by the people. When we send a telegram we must go to a telegraph office in quest of an operator skilled in translating a message into the long and short taps of the Morse code of signals. We are somewhat in the case of the Neapolitan who cannot write, and who must seek a professional scribe to assist him in communications, however confidential. From this dependence the telephone proclaims emancipation; it strikes a dominant note of modern invention—immediacy and simplicity. Ousting the middleman as an intruder, it enables anybody who can ring a bell, speak, and listen to be master of electric communication. It is as if a speaking-tube, efficient and clear, were laid between one's house or office and every other in the web that radiates from telephonic headquarters. A speaking-tube confines to a narrow line the vibrations which without it would agitate a roomful of air; hence its carrying power. A telephone limits to a narrower line of metal undulations which are incomparably more minute; hence an effectiveness as much above that of the tube as the mobility of a molecule exceeds that of a mass.

Long-distance Telephony.

At long distances the boon of conversation,—of receiving an instant reply to a question, has special value. A patient confers with his surgeon, a railroad president with his counsel, an investor with his broker, as if they stood face to face. Because of this new facility the railroads between New York and Chicago are suffering a noteworthy loss of business; their rapid trains are less in request than formerly. Principals and agents, clients and attorneys, now find it unnecessary to travel a thousand miles that their voices may be accompanied by themselves. Experiments of promise have been made in relaying the telephone, so that, as in the case of the telegraph, a message may be sent to an indefinitely great distance by means of local currents brought here and there into the line. The human voice may yet belt the earth, and this before many years are past.

It has been found possible to send several telephonic messages simultaneously over the same wire, either in one direction, or in opposite directions. Should these experiments issue in commercial success the telegraph will find its rival formidable indeed. In the hands of Dr. Lodge the telephone has been refined to thirtyfold its ordinary sensitiveness, in which form it is an unapproached means of revealing minute electric currents. To pass to the other extreme of telephonic capacity, Edison, in constructing his megaphone, enables an assembly of a thousand persons to hear an oration, an orchestra, or a chorus borne upon electric waves for a distance of a hundred miles and more. In services of a more every-day kind let us mark the good offices of the ordinary instrument.

The acute responsiveness of the ordinary telephone at first seemed a serious barrier to its use for long distances. In a range of miles its wire was liable to come into the neighbourhood of telegraphic, lighting, or power circuits, whose pulsations it reported all too faithfully. The difficulty lay in balancing each disturbance by an equal and opposite disturbance, which problem, a little at a time, has been duly solved. The first improvement was in making each line double, so as to discard the " earth," borrowed from telegraphy, as the return half of the circuit. This greatly reduced many perturbing influences, and barred out others completely. Another and more decided betterment lay in making the two wires of a circuit cross each other, without touching, at every mile the upper wire exchanging its place with the lower wire. This plan provides effectual compensation for inductive intrusions, leaving to the engineer the simple question of furnishing better metallic conductors. This he has done, first, by using hard drawn copper wire instead of iron, and next, by employing this in a size which at the end of 1899 had reached .165 of an inch. Among the cities most distant from each other which, on December 31, 1899, were in telephonic communication were San Francisco and Boise City, 1309 miles apart; Boston and Montgomery, 1538 miles; Boston and Omaha, 1556; Seattle and San Diego, 1567; Boston and Kansas City, 1609; Boston and Duluth, 1652; and Boston and Little Rock, 1793 miles. In this last case the two wires which form the circuit weigh in all no less than 780 tons; this huge mass is to be exceeded by that of the line, 1859 miles in length, soon to connect New York with New Orleans.

Manifold New Benefits.

Whether for distances long or short, the telephone confers something like ubiquity upon the human voice. Physicians are summoned in emergency without the loss of a moment; from one's arm-chair a lawyer or a banker may be consulted as readily as by a formal visit; a manufacturer from his down-town office gives orders to his foreman in a distant suburb; housekeepers go to market every morning without taking off their slippers; and merchants dispose of their wares without the costly travel previously required. In the first critical minute of a fire an alarm reaches headquarters, and when an accident happens on a trolley line help is forthwith despatched from the nearest station. In the police departments of American cities the telephone has unique value, especially when foreigners on the force are not too familiar with English spoken or written. In such cases needed explanations can be given, and, what is of equal consequence, a speaker may be identified by his voice as the officer authorised to command.

By its means the chief at headquarters is in touch with every member of the force at times of uncommon peril. When a great holiday parade is to be escorted with safety to the hosts of spectators who press almost beneath the feet of its horses, when a riotous mob is to be headed off and dispersed, when an explosion or a hurricane involves a city in disaster, the telephone gives a control much more constant and direct than is possible to the telegraph. In many situations the telephone enters where the speaking-tube has no admittance and the telegraph-wire is scarcely feasible. In compressed-air caissons and diving work the fluctuations of pressure and the need for perfect flexibility bar out a rigid tube, as well as the telegraph instrument with its liability to harm. In mines the distances are usually too long for tubing, and noises assail even short lengths of pipe with confusing effect. In cold-storage warehouses another difficulty is confronted, as the condensation of moisture inside a pipe may render it worthless. A telephonic wire in all these circumstances comes in with perfect flexibility, with imperviousness to sound, with indifference to pressure, and a trifling cost. Even within what at first seemed an unassailable stronghold, the speaking-tube is being supplanted. In a factory the desks of the chiefs of departments are now being united by telephones with the head office; so, too, in great warehouses, stores, and hotels. In the largest new office buildings, all the tenants are in telephonic communication with the superintendent and with one another.

As a rule a telephone exchange is nothing more than a passive agent, resting content with responding to Mr. Brown's request that he be put in communication with Mr. Smith. But the exchange may perform other duties than these. A subscriber may be called up at any hour in the morning he wishes; in case of a fire in or near his business premises he may be duly warned. Among the singular examples of this kind of aid may be mentioned the arousal of subscribers desirous of witnessing the meteors expected every autumn in November. Their appearance is somewhat irregular, so that a single watcher of the skies replaces the thousand throughout a great metropolis who might otherwise waste their time.

Sometimes lines of metal laid for a very different purpose lend themselves to telephony as well as if they had been designed for nothing else. Barbed-wire fences not only mark the bounds of a Kansas farm, or an Australian cattle-run, but furnish admirable telephonic circuits.[1] In this they are beginning to ameliorate the isolation of country life. When roads are heavy, or impassable, and indeed at all times, a neighbourly word of greeting and gossip is more cheery than any written communications can ever be.

The telephone, despite all attempts to provide it, still lacks a simple and trustworthy record; the hopes built upon the phonograph in this regard remain unfulfilled. This is why the ticker, which prints the news in thousands of American offices and clubs, has never been ousted by the Budapest plan of a continuous news service by telephone. In circumstances where the telegraph is debarred

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[1] Liberal, Kansas, is a centre of such improvised means of communication. Mr. George S. Smith writes thence, July 4, 1899: "The use of the common wire fence as a conductor is sufficient on short lines of ten to fifteen miles in dry weather. The wire carefully connected, no solder is needed. In wet weather the fence wire makes a poor connection. We have a line thirty-five miles long, using the fence in place of poles, driving the nail through the insulator into the top of the post. This makes a good line at small expense."

A rural telephone service is far advanced in northeastern Ohio, and particularly in Geauga County, which is strictly an agricultural county. Not only is there an office in every township, but hundreds of farmers have telephones in their homes. One of the companies, the Bainbridge, is strictly a farmers' company, it being operated by eight farmers, who own everything from franchise to switchboard. The primary object in constructing the lines was not

PLATE VI

CHINESE TELEPHONE SUBSTATION.

Pacific Telephone and Telegraph Co., San Francisco.

from the direct conveyance of word-symbols, the telephone enters with peculiar value. Until Professor Bell perfected this invention a Chinaman was denied by the structure of his language any immediate transmission of it by electricity. Chinese has no alphabet, and its written signs are so numerous and intricate as to defy reduction to a simple telegraphic code. Two methods proffered themselves: first, to translate a Chinese message into an alphabetical tongue, telegraph this, and at the receiving-station run the risk of error in retranslating into Chinese; second, in the original Morse method, giving a number to each word in a dictionary, and telegraphing numerals, to be matched as received with their appropriate signification.

A Godsend to the Chinaman.

With the telephone all this hazard and trouble vanish at once. A Chinaman speaks his message; it is received exactly as spoken, either by his correspondent or his correspondent's scribe. Mr. Louis Glass, of the Pacific Telephone and Telegraph Company, San Francisco, states that his company has a substation in San Francisco, employing three Chinese attendants. "Their ejaculatory language gives peculiarly good telephonic results. The Chinese do a very large long-distance business throughout the whole Pacific coast, and apparently with more satisfactory results than English-

to build them for an investment, but as a help in the transaction of business, and to give families some of the social privileges that are too often lacking on the farm. A modern 100-drop switchboard is centrally located in the home of one of the company, who, with the help of his family, attends to this work very satisfactorily. The rental price of a telephone is only $12 a year in advance, or $1.25 by the month, and this entitles the subscriber, his family, hired help, and guests to the free use of the lines, and also of those with which the company has reciprocity contracts. This company started with three subscribers outside its organisers, and now it has more than fifty, with thirty miles of poles, and one hundred of wire. The low rental is only made possible in the country by placing several telephones in each circuit, usually one street or neighbourhood being on the same wire.—*American Agriculturist*, October 7, 1899.

speaking subscribers" (Plate VI). In British Columbia, the Victoria Telephone Company reports a similar success with a circle of Chinese subscribers, some fifty in number.

Local and Long-distance Systems as Combined in Sweden.

In New York, Chicago, and other large American cities, the telephones used for local circuits are available for long-distance operation, so that a subscriber from his office-desk or parlor-table may talk a mile or a thousand miles with equal facility. In Stockholm the telephone service is noteworthy for its cheapness, and for its union of a network of communication which extends throughout Sweden from the nucleus afforded by the local systems of the capital. In Stockholm, with a population of 283,000, there were on August 15, 1899, no fewer than 24,179 subscribers to the three installations. Two of these, the Allmanna and the Bell, had 19,020 subscribers; the third, which is a government service, had 5159. Accepting the usual number of a household as being six, we have thus a telephone for every two households in the Scandinavian capital. The lowness of charges has had much to do with this unexampled popularity of the instrument. The Allmanna allows a subscriber to have an independent line, and unlimited use of it, for 80 crowns ($21.60) a year. If he will share his line with another subscriber, the charge falls to 60 crowns ($16.20). The Bell Company serves residences solely; it furnishes each subscriber with an independent line for 36 crowns ($9.72) a year; for every conversation beyond 100 in each quarter a toll of 10 ore ($2\frac{7}{10}$ cents) is levied.

If a subscriber to the Allmanna Company chooses to pay 100 crowns ($27) a year, he may converse with the Bell subscribers to his heart's content. Without extra payment the subscribers to both concerns may talk to 3850 subscribers in the country surrounding Stockholm for a radius of forty-five miles. A country subscriber has privileges wider still. He is at liberty to talk within a radius of ninety miles from home without extra charge. Mr. H. T. Cedergren of the Allmanna Company, who courteously gives me this information, estimated the total number of telephones in Sweden in use on August 15, 1899, as about 65,000 for a total population of 4,900,000. In establishing a tariff on the lowest possible terms, and graduating its charges according to the services rendered, the example of Sweden is one that points the way to a popularity for the telephone such as it has not had elsewhere in the civilised world.

The Telephone and the Telegraph as Rivals.

Long-distance telephony exerts a rivalry with the telegraph which grows keener month by month, as the network of arteries for electric speech extends farther from North to South, from East to West, so that the question suggests itself, Will this rivalry gain strength in the future? The main advantage of the telegraph is that a positive record is on file at each end of the line. When one writes a message and leaves it with a telegraph clerk his task is at an end; he need waste no time waiting, perhaps nearly an hour, while the line is "busy." The telegraph, too, can send news to a hundred or more offices at a single sending operation, and with the aid of machinery can far outspeed the voice. The strong points of the telephone, on the other hand, are its simplicity and immediacy, from which, however, must be subtracted the disadvantage that, contrary to a general rule, the larger a telephonic exchange the more does the installation cost per subscriber. In the first place, the average wire is much longer in a great city like New York than in Buffalo, a community but one-sixth as populous; and secondly, a switchboard and its accessories when doubled in extent demand a more than doubled outlay; while, too, the larger a city the greater is the average number of calls per subscriber. In many ways a telephone and a telegraph system may supplement each other most usefully. A message of only ordinary importance may be intrusted through the telephone to a telegraph office for transmission, and vice versa. In many cases an order including figures of moment is sent by telephone, and for safety's sake these figures, by themselves, are also telegraphed. Considering the fact that this is an era when men of capital combine rather than divide, the prospect seems to be that the old and the new modes of electric communication may before many years have but one headship and a common purse.

A Marvel of Sensitiveness.

In work strictly scientific the telephone widens the range of the ear as much as the microscope enlarges that of the eye. The ear is really sensitive to a degree unsuspected before the invention of Professor Bell measured its responsiveness. Sound may be distinctly heard through a telephonic disc whose motion involves next to no energy at all. It is estimated that an electric current derived from a pound-weight in slowly descending one foot could keep up an audible sound in an ordinary telephone for three thousand years; and that a sixteen-candle-power lamp receives a current strong enough to yield an audible signal in sixty million million telephones of the refined type due to Professor Lodge. Hence the exquisite sensitiveness of the instrument when flaws are to be found in metal shafts or plates, when breaks are to be located in ocean cables, or an infinitesimal current is to be detected in its escape from insulation. The main incitement in the quest for new substances is the hope that they may be found to possess certain desired properties. An instrument such as the telephone which enables us to observe the behaviour of familiar steel or copper from fresh sides, does as much as if it gave us substances unknown before.

At this point we are brought to consider electricity as an educator and quickener of the senses. Operators who listen intently hour after hour at the telephone, develop an acuteness well-nigh magical in fixing the point at which a cable has parted under the sea, or one land wire has crossed another. When telegraphs were first installed in America their messages were indented on paper registers; but very soon the operators were able to receive the words by ear instead of through the eye. The "sounders" of every telegraph office in America testify to the commonness of a faculty once deemed rare, that is to-day widely cultivated as a means of livelihood. Expert telegraphers now transmit as many as fifty words a minute when the messages and the words are short; they receive and immediately typewrite such messages at the same speed.

Electricity and the Senses.

In large telephonic exchanges, and other places where peace and quiet are desired, small electric lamps are lighted by way of signal, instead of ringing bells. So sensitive do attendants become that lamps of the tiniest size are sufficient. The most exacting field of electrical communication is that of ocean cables. Here Mr. A. E. Kennelly says: "So accurate does a skilled operator become that he may work steadily eight hours a day sending and receiving messages, yet not fall into one error in a whole month's work." What this means in precision of eye may be comprehended in some measure by casting a glance at the broken curves of a telegram as they swing out from a cable wire (Fig. 63). An ancient dictum of philosophy tells us that there is nothing in the mind that has not been in the senses. To give the senses new alertness and impressibility, to add to the eye, the ear, and the hand instruments a thousandfold more delicate, is clearly to lift research to new heights and offer it horizons unimagined before.

Of all the progeny of the telephone none is more amazing than the photophone, also created by Professor Alexander Graham Bell. The telephone employs electricity as its

The Photophone.

intermediary between sound from the lip and sound striking the ear; the photophone for the like mediation uses light instead of electricity. Milton in a famous passage pictures Uriel sliding from heaven to earth on a sunbeam; if the poet had bidden him speak through the sunbeam so that he need not have descended from the sky, he would not have more boldly departed from unpoetical facts—as facts were within the ken of practical men in the seventeenth century.[1] For simplicity the photophone is comparable with the telephone itself (Fig. 79). A speaker directs his voice upon a mirror of flexible mica, or microscope glass, *B*. Upon *B* light is thrown from the sun or a powerful lamp by the mirror *M* and the lenses *A* and *L*. As *B* vibrates in unison with the voice the rays of light reflected from *B* through the lens *R* to the distant parabolic mirror *CC* have undulations corresponding to those of the spoken words. How shall light enable us to hear these words? Selenium has already been mentioned as heightened in electrical conductivity when light shines upon it; that conductivity, of course, will vary when light of varying intensity, as in this case, impinges

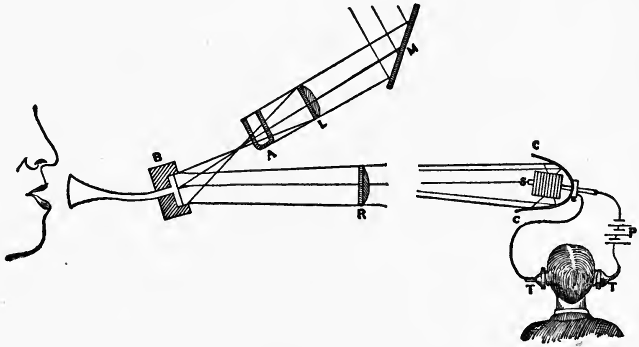

FIG. 79.
Photophone.

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[1] *Paradise Lost*, Book IV, line 555.

upon it. The arriving beam is focussed upon a selenium receiver, *S*, connected with a voltaic cell, *P*, and the telephonic ear-pieces *T*, *T*, with the marvellous effect that the message is distinctly heard.

Why, it may be asked, has not the photophone, invented as long ago as 1880, been exhibited to the public as freely as the radioscope, devised as recently as 1896? The answer is that to secure a beam of light sufficiently uniform is so difficult that experiments on a popular scale are most troublesome. Variations of light, too small for detection by the eye, give rise to disturbing noises in the receiver. Again, the photophone has no such practical utility as the radioscope, at least for the present; so long as messages can be sent by better means, the luminous ray will not be added to the resources of verbal communication. Professor Bell has discovered that he may on occasion dispense with the photophone, that the unassisted ear receives sounds directly from intermittent light, and, further, that all substances whatever, carbon in the form of lampblack particularly, are excited to sonorous vibration by a flickering ray. Here in an unexpected quarter is confirmation of two general laws formulated long ago: first, that all properties in some degree or other are present in all forms of matter; second, that a property may be, and usually is, pre-eminently manifested in a single substance. We are apt to think of light and sound as unrelated modes of motion; the photophone shows us how easily one may become the other and then return to its first estate.

Seeing through Wires.

The singular responsiveness of selenium to light is at the foundation of a plan for seeing at long range, through wires. An image is to be represented by squares black and white, arranged sampler fashion. Behind each square is to be a selenium cell affected, in its electric current, by the blackness or whiteness in front of it. Each cell is to be then connected with a distant partner cell, which will show a black or white disc according as the received current is strong or weak. The assemblage of these second repeating-discs will afford the image anew. The many wires indispensable to this scheme place it among the ingenious suggestions that demand so large an outlay as to remain suggestions merely.

CHAPTER XVIII

ELECTRICITY—A REVIEW AND A PROSPECT

Energy in its Best Phase.

LET us compare electricity with its precursor, fire, and we shall understand the revolution by which fire is now in so many tasks supplanted by the electric pulse which, the while, creates for itself a thousand fields denied to flame. Copper is an excellent thermal conductor, and yet it transmits heat almost infinitely more slowly than it conveys electricity. One end of a thick copper rod ten feet long may be safely held in the hand while the other end is heated to redness, yet one millionth part of this same energy, if in the form of electricity, would traverse the rod in $\frac{1}{100,000,000}$ part of a second. Compare next electricity with light, often the companion of heat. Light travels in straight lines only; electricity can go round a corner every inch for miles, and, none the worse, yield a brilliant beam at the end of its journey. Indirectly, therefore, electricity enables us to conduct either heat or light as if both were flexible pencils of rays, and subject to but the smallest tolls in their travel.

We have remarked upon such methods as those of the electric welder which summon intense heat without fire, and we have glanced at the electric lamps which shine just because combustion is impossible through their rigid exclusion of air. Then for a moment we paused to look at the plating baths which have developed themselves into a commanding rivalry with the blaze of the smelting furnace, with the flame which from time immemorial has filled the ladle of the founder and moulder. Thus methods that commenced in dismissing flame end boldly by dispossessing heat itself. But, it may be said, this usurping electricity usually finds its source, after all, in combustion under a steam-boiler. True, but mark the harnessing of Niagara, of the Lachine Rapids near Montreal, of a thousand streams elsewhere. In the near future motive power of nature's giving is to be wasted less and less, and perforce will more and more exclude heat from the chain of transformations which issue in the locomotive's flight, in the whirl of factory and mill. Thus in some degree is allayed the fear, never well grounded, that when the coal-fields of the globe are spent civilisation must collapse. As the electrician hears this foreboding he recalls how much fuel is wasted in converting heat into electricity. He looks beyond either turbine or shaft turned by wind or tide, and, remembering that the metal dissolved in his battery yields at his will its full content of energy, either as heat or electricity, he asks, Why may not coal or forest tree, which are but other kinds of fuel, be made to do the same?

Heat Banished.

One of the earliest uses of light was as a means of communicating intelligence, and to this day the signal lamp and the red fire of the mariner are as useful as of old. But how much wider is the field of electricity as it creates the telegraph and the telephone! In the telegraph we have all that a pencil of light could be were it as long as an equatorial girdle and as flexible as a silken thread. In the telephone for nearly two thousand miles the pulsations of a speaker's voice are not only audible, but retain their characteristic tones.

Perfected Communication.

Supreme Versatility.

In the field of mechanics electricity is decidedly preferable to any other agent. Heat may be transformed into motive power by a suitable engine, but there its adaptability is at an end. An electric current drives not only a motor, but every machine and tool attached to the motor, the whole executing tasks of a delicacy and complication new to industrial art. On an electric railroad an identical current propels the train, directs it by telegraph, operates its signals, provides it with light and heat, while it stands ready to give constant verbal communication with any station on the line, if this be desired.

In the home electricity has equal versatility, at once promoting healthfulness, refinement, and safety. Its tiny button expels the hazardous match as it lights a lamp which sends forth no baleful fumes. An electric fan brings fresh air into the house—in summer as a grateful breeze. Simple telephones, quite effective for their few yards of wire, give a better because a more flexible service than speaking-tubes. Few invalids are too feeble to whisper at the light, portable ear of metal. Sewing-machines and the more exigent apparatus of the kitchen and laundry transfer their demands from flagging human muscles to the tireless sinews of electric motors—which ask no wages when they stand unemployed. Similar motors already enjoy favour in working the elevators of tall dwellings in cities. If a householder is timid about burglars, the electrician offers him a sleepless watchman in the guise of an automatic alarm; if he has a dread of fire, let him dispose on his walls an array of thermometers that at the very inception of a blaze will strike a gong at headquarters. But these, after all, are matters of minor importance in comparison with the foundations upon which may be reared, not a new piece of mechanism, but a new science or a new art.

In the recent and swift subjugation of the territory open

Electricity in the Field of Research.

alike to the chemist and the electrician, where each advances the quicker for the other's company, we have fresh confirmation of an old truth—that the boundary lines which mark off one field of science from another are purely artificial, are set up only for temporary convenience. The chemist has only to dig deep enough to find that the physicist and himself occupy common ground. "Delve from the surface of your sphere to its heart, and at once your radius joins every other." Even the briefest glance at electrochemistry should pause to acknowledge its profound debt to the new theories as to the bonding of atoms to form molecules, and of the continuity between solution and electrical dissociation. However much these hypotheses may be modified as more light is shed on the geometry and the journeyings of the molecule, they have for the time being recommended themselves as finder-thoughts of golden value. These speculations of the chemist carry him back perforce to the days of his childhood. As he then joined together his black and white bricks he found that he could build cubes of widely different patterns. It was in propounding a theory of molecular architecture that Kekulé gave an impetus to a vast and growing branch of chemical industry—that of the synthetic production of dyes and allied compounds.

It was in pure research, in paths undirected to the market-place, that such theories have been thought out. Let us consider electricity as an aid to investigation conducted for its own sake. The chief physical generalisation of our time, and of all time, the persistence of force, emerged to view only with the dawn of electric art. When it was observed that electricity might become heat, light, chemical action, or mechanical motion, that in turn any of these might produce electricity, it was at once indicated that all these phases of energy might differ from each other only as the movements in circles, volutes, and spirals of ordinary mechanism. The suggestion was confirmed when electrical measurers were refined to the utmost precision, and a single quantum of energy was revealed a very Proteus in its disguises, yet beneath these disguises nothing but constancy itself.

"There is that scattereth, and yet increaseth; and there is that withholdeth more than is meet, but it tendeth to poverty." Because the geometers of old patiently explored the properties of the triangle, the circle, and the ellipse, simply for pure love of truth, they laid the corner-stones for the arts of the architect, the engineer, and the navigator. In like manner it was the disinterested work of investigation conducted by Ampère, Faraday, Henry, and their compeers in ascertaining the laws of electricity which made possible the telegraph, the telephone, the dynamo, and the electric furnace. The vital relations between pure research and economic gain have at last worked themselves clear. It is perfectly plain that a man who has it in him to discover laws of matter and energy does incomparably more for his kind than if he carried his talents to the mint for conversion into coin. The voyage of a Columbus may not immediately bear as much fruit as the uncoverings of a mine prospector, but in the long run a Columbus makes possible the finding many mines which without him no prospector would ever see. Therefore let the seed-corn of knowledge be planted rather than eaten. But in choosing between one research and another it is impossible to foretell which may prove the richer in its harvests; for instance, all attempts thus far economically to oxidise carbon for the production of electricity have failed, yet in observations that at first seemed equally barren have lain the hints to which we owe the incandescent lamp and the wireless telegraph.

Perhaps the most promising field of electrical research is that of discharges at high pressures; here the leading

American investigators are Professor John Trowbridge and Professor Elihu Thomson. Employing a tension estimated at one and a half million volts, Professor Trowbridge has produced flashes of lightning six feet in length in atmospheric air; in a tube exhausted to one-seventh of atmospheric pressure the flashes extended themselves to forty feet. According to this inquirer, the familiar rending of trees by lightning is due to the intense heat developed in an instant by the electric spark; the sudden expansion of air or steam in the cavities of the wood causes an explosion. The experiments of Professor Thomson confront him with some of the seeming contradictions which ever await the explorer of new scientific territory. In the atmosphere an electrical discharge is facilitated when a metallic terminal (as a lightning-rod) is shaped as a point; under oil a point is the form least favourable to discharge. In the same line of paradox it is observed that oil steadily improves in its insulating effect the higher the electrical pressure committed to its keeping; with air as an insulator the contrary is the fact. These and a goodly array of similar puzzles will, without doubt, be cleared up as students in the twentieth century pass from the twilight of anomaly to the sunshine of ascertained law.

"Before there can be applied science there must be science to apply," and it is by enabling the investigator to know nature under a fresh aspect that electricity rises to its highest office. The laboratory routine of ascertaining the conductivity, polarisability, and other electrical properties of matter is dull and exacting work, but it opens to the student new windows through which to peer at the architecture of matter. That architecture, as it rises to his view, discloses one law of structure after another; what in a first and clouded glance seemed anomaly is now resolved and reconciled; order displays itself where once anarchy alone appeared. When the investigator now needs a substance of peculiar properties he knows where to find it, or has a hint for its creation—a creation perhaps new in the history of the world. As he thinks of the wealth of qualities possessed by his store of alloys, salts, acids, alkalies, new uses for them are borne into his mind. Yet more—a new orchestration of inquiry is possible by means of the instruments created for him by the electrician, through the advances in method which these instruments effect. With a second and more intimate point of view arrives a new trigonometry of the particle, a trigonometry inconceivable in pre-electric days. Hence a surround is in progress which early in the twentieth century may go full circle, making atom and molecule as obedient to the chemist as brick and stone are to the builder now.

The laboratory investigator and the commercial exploiter of his discoveries have been by turns borrower and lender, to the great profit of both. What Leyden jar could ever be constructed of the size and revealing power of an Atlantic cable? And how many refinements of measurement, of purification of metals, of precision in manufacture, have been imposed by the colossal investments in deep-sea telegraphy alone! When a current admitted to an ocean cable, such as that between Brest and New York, can choose for its path either 3540 miles of copper wire or a quarter of an inch of gutta-percha, there is a dangerous opportunity for escape into the sea, unless the current is of nicely adjusted strength, and the insulator has been made and laid with the best-informed skill, the most conscientious care. In the constant tests required in laying the first cables Lord Kelvin (then Professor William Thomson) felt the need for better designed and more sensitive galvanometers or current measurers. His great skill both as a mathematician and a mechanician created the existing instruments, which seem beyond improvement. They serve not only in commerce and manufacture, but in promoting the strictly scientific work of the laboratory. Now that electricity purifies copper as fire cannot, the mathematician is able to treat his problems of long-distance transmission, of traction, of machine design, with an economy and certainty impossible when his materials were not simply impure, but impure in varying and indefinite degrees. The factory and the workshop originally took their magneto-machines from the experimental laboratory; they have returned them remodelled beyond recognition as dynamos and motors of almost ideal effectiveness.

A galvanometer actuated by a thermo-electric pile furnishes much the most sensitive means of detecting changes of temperature; hence electricity enables the physicist to study the phenomena of heat with new ease and precision. It was thus that Professor Tyndall conducted the classical researches set forth in his *Heat as a Mode of Motion*, ascertaining the singular power to absorb terrestrial heat which makes the aqueous vapour of the atmosphere act as an indispensable blanket to the earth.

The Universe Enlarged.

And how vastly has electricity, whether in the workshop or laboratory, enlarged our conceptions of the forces that thrill space, of the substances, seemingly so simple, that surround us—substances that propound questions of structure and behaviour that silence the acutest investigator. "You ask me," said a great physicist, "if I have a theory of the *universe?* Why, I have n't even a theory of *magnetism!*"

The conventional phrase "conducting a current" is now understood to be mere figure of speech; it is thought that a wire does little else than give direction to electric energy. Pulsations of high tension have been proved to be mainly superficial in their journeys, so that they are best conveyed (or convoyed) by conductors of tubular form. And what is it that moves when we speak of conduction? It seems to be now the molecule of atomic chemistry, and anon the same ether that undulates with light or radiant heat. Indeed, the conquest of electricity means so much because it impresses the molecule and the ether into service as its vehicles of communication. Instead of the old-time masses of metal, or bands of leather, which moved stiffly through ranges comparatively short, there is to-day employed a medium which may traverse 186,400 miles a second, and with resistances most trivial in contrast with those of mechanical friction.

And what is friction in the last analysis but the production of motion in undesired forms, the allowing valuable energy to do useless work? In that amazing case of long-distance transmission, common sunshine, a solar beam arrives at the earth from the sun not one whit the weaker for its excursion of 92,000,000 miles. It is highly probable that we are surrounded by similar cases of the total absence of friction in the phenomena of both physics and chemistry, and that art will come nearer and nearer to nature in this immunity is assured when we see how many steps in that direction have already been taken by the electrical engineer. In a preceding page a brief account was given of the theory that gases and vapours are in ceaseless motion. This motion suffers no abatement from friction, and hence we may infer that the molecules concerned are perfectly elastic. The opinion is gaining ground among physicists that all the properties of matter, transparency, chemical combinability, and the rest, are due to immanent motion in particular orbits, with diverse velocities. If this be established, then these motions also suffer no friction, and go on without resistance forever.

As the investigators in the vanguard of science discuss the constitution of matter, and weave hypotheses more or less fruitful as to the interplay of its forces, there is a growing faith that the day is at hand when the tie between electricity and gravitation will be unveiled—when the reason why matter has weight will cease to puzzle the thinker. Who can tell what relief of man's estate may be bound up with the ability to transform any phase of energy into any other without the circuitous methods and serious losses of to-day! In the sphere of economic progress one of the supreme advances was due to the invention of money, the providing a medium for which any saleable thing may be exchanged, with which any purchasable thing may be bought. As soon as a shell, or a hide, or a bit of metal was recognised as having universal convertibility, all the delays and discounts of barter were at an end. In the world of physics and chemistry the corresponding medium is electricity; let it be produced as readily as it produces other modes of motion, and human art will take a stride forward such as when Volta disposed his zinc and silver discs together, or when Faraday set a magnet moving around a copper wire.

Electricity not an Infant.

For all that the electric current is not as yet produced as economically as it should be, we do wrong if we regard it as an infant force. However much new knowledge may do with electricity in the laboratory, in the factory, or in the exchange, some of its best work is already done. It is not likely ever to perform a greater feat than placing all mankind within ear-shot of each other. Were electricity unmastered there could be no democratic government of the United States. To-day the drama of national affairs is more directly in view of every American citizen than, a century ago, the public business of Delaware could be to the men of that little State. And when on the broader stage of international politics misunderstandings arise, let us note how the telegraph has modified the hard-and-fast rules of old-time diplomacy. To-day, through the columns of the press, the facts in controversy are instantly published throughout the world, and thus so speedily give rise to authoritative comment that a severe strain is put upon negotiators whose tradition it is to be both secret and slow.

Railroads, with all they mean for civilisation, could not have extended themselves without the telegraph to control them. And railroads and telegraphs are the sinews and nerves of national life, the prime agencies in welding the diverse and widely separated States and Territories of the Union. A Boston merchant builds a cotton-mill in Georgia; a New York capitalist opens a copper-mine in Arizona. The telegraph which informs them day by day how their investments prosper tells idle men where they can find work, where work can seek idle men. Chicago is laid in ashes, Charleston topples in earthquake, Johnstown is whelmed in flood, and instantly a continent springs to their relief. And what benefits issue in the strictly commercial uses of the telegraph! At its click both locomotive and steamship speed to the relief of famine in any quarter of the globe. In times of plenty or of dearth the markets of the world are merged and are brought to every man's door. Not less striking is the neighbourhood guild of science, born, too, of the telegraph. The day after Röntgen announced his X rays, physicists on every continent were repeating his experiments—were applying his discovery to the healing of the wounded and diseased. Let an anti-toxin for diphtheria, consumption, or yellow fever be proposed, and a hundred investigators the world over bend their skill to confirmation or disproof, as if the suggestor dwelt next door.

Social Benefits.

On a stage less dramatic, or rather not dramatic at all, electricity works equal good. Its motor freeing us from dependence on the horse is spreading our towns and cities into their adjoining country. Field and garden compete with airless streets. The sunny cottage is in active rivalry with the odious tenement-house. It is found that transportation within the gates of a metropolis has an importance second only to the means of transit which links one city with another. The engineer is at last filling the gap which too long existed between the traction of horses and that of steam. In point of speed, cleanliness, and comfort such an electric subway as that of South London leaves nothing to be desired. Throughout America electric roads, at first suburban, are now fast joining town to town and city to city, while, as auxiliaries to steam railroads, they place sparsely settled communities in the arterial current of the world, and build up a ready market for the dairyman and the fruit-grower. In its saving of what Mr. Oscar T. Crosby has called "man-hours" the third-rail system is beginning to oust steam as a motive power from trunk-lines. Already shrewd railroad managers are granting partnerships to the electricians who might otherwise encroach upon their dividends. A service at first restricted to passengers has now extended itself to the carriage of letters and parcels, and begins to reach out for common freight. We may soon see the farmer's cry for good roads satisfied by good electric lines that will take his crops to market much more cheaply and quickly than horses and macadam ever did. In cities, electromobile cabs and vans steadily increase in numbers, furthering the quiet and cleanliness introduced by the trolley car.

Municipal Electricity.

A word has been said about the blessings which electricity promises to country folk, yet greater are the boons it stands ready to bestow in the hives of population. Until a few decades ago the water-supply of cities was a matter not of municipal but of individual enterprise; water was drawn in large part from wells here and there, from lines of piping laid in favoured localities, and always insufficient. Many an epidemic of typhoid fever was due to the contamination of a spring by a cesspool a few yards away. To-day a supply such as that of New York is abundant and cheap because it enters every house. Let a centralised electrical service enjoy a like privilege, and it will offer a current which is heat, light, chemical energy, or motive power, and all at a wage lower than that of any other servant. Unwittingly, then, the electrical engineer is a political reformer of high degree, for he puts a new premium upon ability and justice at the City Hall. His sole condition is that electricity shall be under control at once competent and honest. Let us hope that his plea, joined to others as weighty, may quicken the spirit of civic righteousness so that some of the richest fruits ever borne in the garden of science and art may not be proffered in vain. Flame, the old-time servant, is individual; electricity, its successor and heir, is collective. Flame sits upon the hearth and draws a family together; electricity, welling from a public source, may bind into a unit all the families of a vast city, because it makes the benefit of each the interest of all.

Baseless Hopes.

But not every promise brought forward in the name of the electrician has his assent or sanction. So much has been done by electricity, and so much more is plainly feasible, that a reflection of its triumphs has gilded many a baseless dream. One of these is that the cheap electric motor, by supplying power at home, will break up the factory system, and bring back the domestic manufacturing of old days. But if this power cost nothing at all the gift would leave the factory unassailed; for we must remember that power is being steadily reduced in cost from year to year, so that in many industries it has but a minor place among the expenses of production. The strength and profit of the factory system lie in its assembling a wide variety of machines, the first delivering its product to the second for another step toward completion, and so on until a finished article is sent to the wareroom. It is this minute subdivision of labour, together with the saving and efficiency that inure to a business conducted on an immense scale under a single manager, that bids us believe that the factory has come to stay. To be sure, a weaver, a potter, or a lens-grinder of peculiar skill may thrive at his loom or wheel at home; but such a man is far from typical in modern manufacture. Besides, it is very questionable whether the lamentations over the home industries of the past do not ignore evil concomitants such as still linger in the home industries of the present—those of the sweater's den, for example.

A New and Supreme Resource.

This rapid survey of what electricity has done and may yet do—futile expectation dismissed—has shown it the creator of a thousand material resources, the perfecter of that communication of things, of power, of thought, which in every prior stage of advancement has marked the successive lifts of humanity. It was much when the savage loaded a pack upon a horse or an ox instead of upon his own back; it was yet more when he could make a beacon-flare give news or warning to a whole country-side, instead of being limited to the messages which might be read in his waving hands. All that the modern engineer was able to do with steam for locomotion is raised to a higher plane by the advent of his new power, while the long-distance transmission of electrical energy is contracting the dimensions of the planet to a scale upon which its cataracts in the wilderness drive the spindles and looms of the factory town, or illuminate the thoroughfares of cities. Beyond and above all such services as these, electricity is the corner-stone of physical generalisation, a revealer of truths impenetrable by any other ray.

The subjugation of fire has done much in giving man a new independence of nature, a mighty armoury against evil. In curtailing the most arduous and brutalising forms of toil, electricity, that subtiler kind of fire, carries this emancipation a long step further, and, meanwhile, bestows upon the poor many a luxury which but lately was the exclusive possession of the rich. In more closely binding up the good of the bee with the welfare of the hive, it is an educator and confirmer of every social bond. In so far as it proffers new help in the war on pain and disease it strengthens the confidence of man in an Order of Right and Happiness which for so many dreary ages has been a matter rather of hope than of vision. Are we not, then, justified in holding electricity to be a multiplier of faculty and insight, a means of dignifying mind and soul, unexampled since man first kindled fire and rejoiced?

We have traced how dexterity rose to fire-making, how fire-making led to the subjugation of electricity. Much of the most telling work of fire can be better done by its great successor, while electricity performs many tasks possible only to itself. Unwitting truth there was in the simple fable of the captive who let down a spider's film, that drew up a thread, which in turn brought up a rope—and freedom. It was in 1800, on the threshold of the nineteenth century, that Volta devised the first electric battery. In a hundred years the force then liberated has vitally interwoven itself with every art and science, bearing fruit not to be imagined even by men of the stature of Watt, Lavoisier, or Humboldt. Compare this rapid march of conquest with the slow adaptation, through age after age, of fire to cooking, smelting, tempering. Yet it was partly, perhaps mainly, because the use of fire had drawn out man's intelligence and cultivated his skill that he was ready in the fulness of time so quickly to seize upon electricity and subdue it.

Electricity is as legitimately the offspring of fire as fire of the simple knack in which one savage in ten thousand was richer than his fellows. The principle of permutation, suggested in both victories, interprets not only how a vast empire is won by a new weapon of prime dignity; it explains why such empires are brought under rule with ever-accelerated pace. Every talent only pioneers the way for the richer talents which are born from it.

CHAPTER XIX

THE THRESHOLD OF PHOTOGRAPHY

The Incidental may become Paramount.

IN two remarkable cases we have seen how possessions at first prized for one quality have, quite incidentally, disclosed another which in the end has become of paramount importance. The savage, his attention riveted upon the sharpness of his flints for arrows, chisels, or knives, for ages glanced incuriously when a stone in its flaking struck out sparks. Yet in kindling fire the flint did man a loftier service than when it pointed a spear, or gave edge to a saw or a sword. When stone had given way to bronze, and bronze in turn was displaced by iron, the metal at first was esteemed for its strength alone. That small masses of it found here and there should be lodestones was singular, but nothing more; the fact for ages lay barren of either worth or meaning. To-day, as electric art passes from one new province to another in the expansion of its empire, the query is whether the strength or the magnetism of iron is its chief quality.

Let us observe for a moment human activity in the broad contrasts of the necessary toil of work, and the chosen toil, often more arduous, of play. Modern athletes in training for a boat race or a foot-ball match, sportsmen in stalking Rocky Mountain sheep or hunting the big game of India, show us a reversion to a primal instinct as they undertake labours and undergo hardships of extreme severity for sheer delight in their sport. And in such joy of old, not less than in deliberate exercise of skill, did human art begin. When a primitive armourer had finished making a cudgel he expressed his unexhausted sense of power, his delight in form and colour, by daubing the wood with bands of ochre, by carving upon it rude waves and rounds. If he shaped and sharpened a knife he added a few incised flourishes, to proclaim that there should be beauty as well as use in the thing that he had made. This overbrimming of the cup of life had other manifestations: the early artist scrawled upon the walls of caves, or at the base of cliffs, profiles as crude as those which boys to-day chalk upon barns and fences. Sometimes he pressed and patted a dollop of clay into a human image at first so rude that we wonder whether he meant to make an idol or a doll, an object of worship or a plaything for a child.

Who can retrace at this late day the hint or push that impelled him to all this? It may have been in staining or painting his own body that skill was acquired for his simple patterns, his repeated strokes and curves. His first essay in plastic art may have been incited by the impress left on wet clay when a leaf, or nut, was lifted from the ground. Whatever the material, whether sand, or clay, or common earth, whether spread or moulded with twig, splintered bone, or shell, the moment a likeness of leaf or fruit, of man or beast, was wrought faithfully enough for recognition by another eye, a new morning dawned for the human soul. What had begun in sportive outlines, in mere idle ornament, took root for a thousand harvests of use and beauty. Then arose the art of Representation, the putting sign for substance, semblance for reality, the betokening a thing by its swiftly created outline or image. Thence have sprung sculpture, painting, writing, printing—throughout their later course advancing with equal pace beside that consummate symbolism, articulate speech.

FIG. 80.
Carving from the caves of the Dordogne Valley, France.

Of imitative art in its first unsteady steps few traces have been unearthed: favoured by the durability of their material, some of the best portrayals known are among the oldest. In the caves of the Dordogne Valley, in southern France, there dwelt in the days of the now long-extinct mammoth, hunters who were artists too. Their carvings on bone depict deer and horses with a force and freedom that would do credit to modern pencils (Fig. 80). But depictive art in stages lowly in comparison with the Dordogne carvings would gladden its rude beholders, and spur the talent of every man who had it in him to draw, or paint, or carve with more than common dexterity. There was use as well as delight in these creations, for all their crudity. The roughly hewn totem or emblem, bear, crow, or dog, protected the property of an Indian chief or priest as securely as if he himself stood on guard. From such unwitting heraldry, from the execution of individual portraits of warrior and leader, the artist rose to a composition which depicted a battle or a hunt—at first, we may be sure, with little other success than to provide an aid to the memory of annalists, to keep in remembrance the proud traditions that descended from father to son (Fig. 81).

Primitive Delineation.

Both pictures and figures grew better as their creators gained practice, and as they became more expert in the grinding of pigments, or in the use of tools borrowed from humbler arts, or expressly devised for the primitive studio. Thus it came about at last that the recorder, the priest, the seer, was no longer a mere speaker who had to be present when he told his story. Ages after his death his pictures, images, reliefs, remained to echo his voice to men who had never looked upon his face, and this, perchance, on shores many leagues removed from the artist's home or grave. Art had begun its victory over time and space. Knowledge could now be accumulated as never before: in much a man might now begin where his father had left off. Of the excellence to which American aboriginal art rose in its latest pictures and pictographs, we have hundreds of examples in the volumes of Schoolcraft, and Catlin, and of the United States Bureau of Ethnology. While primitive art was quietly opening a door to new and refined pleasures

FIG. 81.

(From H. R. Schoolcraft, *History, Condition, and Prospects of the Indian Tribes of the United States.* Philadelphia, 1854, Vol. IV, p. 253, plate 32.)

Taken from the shoulder-blade of a buffalo found on the plains in the Comanche country of Texas. Symbolises the strife for the buffalo existing between the Indian and white races. The Indian (1), presented on horseback protected by his shield and armed with a lance, kills a Spaniard (3), the latter being armed with a gun, after a circuitous chase (6). The Spaniard's companion (4), armed with a lance, is also killed. The sun is depicted by 2, the buffalo by 5.

of the eye, it was conferring new values upon old utilities. The art which could indicate a path of safety or the vicinity of a foe, point to hidden stores of food or springs of refreshing water, did quite as much for the safety and comfort of primitive man as his rude stone hammer or even the chance-kindled flame which his roving eye might discern as it glimmered in the distance.

Primitive Representation Held its Path till a Hundred Years Ago.

However far draughtsmen, illuminators, painters, etchers, may have carried verisimilitude, there was no essential advance in imitative art down to the first decade of the nineteenth century. All the company of artists, recent and remote, glorious and inglorious alike, from the earliest to the latest, had but one method in copying nature—to express, line by line, stroke by stroke, what their eyes saw before them. Their vision might be distorted or dull, their brains careless or unfaithful in allying eye with hand; their fingers might be clumsy, their tools or pigments faulty or inadequate. By all this did reproduction fall short of its original, or erroneously surpass it, and set down falsity instead of truth. It was left for the nineteenth century to make the faithful touch of light limn its own impressions with more and more accuracy of form and of colour, with illusions, too, of relief and motion, while images which find no response in the eye are in a most indirect and astonishing manner disclosed to sight. As Photographer man enters upon a new career as Initiator, reserving for his hand and eye those high tasks which they alone may accomplish, deputing to the retina of the camera, to the play of chemic affinity, the labour of seizing every radiance of the earth and sky.

Electric science and art swing upon a hinge of iron. Were it not for the ease and celerity with which iron can take on magnetism and let it go, there would be no electro-magnet as the core of the telegraph instrument, the telephone, the dynamo, and the motor. In some degree or other all substances are magnetic, but most of them in a degree so trifling as virtually to possess no magnetism whatever. Nickel, which in the magnetic hierarchy stands next to iron, has but one-sixtieth its attractive power. While electric art thus turns upon a hinge of iron, photography revolves upon a pivot of silver. All substances, metallic compounds especially, are responsive to light—are altered by it in constitution, with an accompanying change of colour. Yet so pre-eminent in this sensitive quality are the salts of silver that without them it is unlikely that we should have any photography at all. The chameleon nature of silver compounds is foreshown in silver as a simple element; it occurs in three forms, each of distinct hue. If stencils are laid upon a polished silver plate and exposed to direct sunshine for two to three hours, an image may be developed by mercury vapour, as in the Daguerre method, or by such a bath as that used for wet collodion plates. Combined with one and the same proportion of bromine, silver displays six diverse orders of molecular architecture, each having a characteristic tint. In the highly complex structures which silver forms with other proportions of bromine, nitrogen, chlorine, or iodine, its unions are so unstable as to be dissevered by a weightless ray of light, and this in many cases in the fraction of a second. Fortunately, this molecular shattering, for all its swiftness, is commonly attended by decided alterations of colour.

A Pivot of Silver.

Nature's own laboratory was the photographer's anteroom. Generations before his art was so much as a dream the miners at Freiberg, in Germany, had come upon small lumps of ore which excited their keen curiosity. In hue and texture it resembled whitish horn; in the fire it disengaged silver: so it was called horn-silver. Its remarkable peculiarity was that when brought into daylight its hue com-

A Hint from the Mine.

menced at once to change to violet. In due season it was proved to be silver chloride and was successfully imitated by chemic art. Its cousin, silver nitrate, familiar as lunar caustic, had long been noted for a kindred trait: when moistened and spread upon the skin, or other surface, its transparency was quickly changed to opaque blackness as organic salts were formed. This power of light upon silver compounds was a strong hint to many an ingenious mind a century ago. Among them were Schultze, in Germany, and Wedgwood, in England, who saw that here lay the promise of copying outlines by the finger of light itself. Both of them pressed leaves, fern-fronds, and flowers upon paper saturated with silver solution, and allowed sunshine to fall upon the paper and the objects laid upon it. Then, for the first time since man appeared upon earth, his hand and eye were freed from the drudgery of catching a contour. His eye, however poor in observation, his hand, let it lack skill as it might, sufficed to bring together the object to be outlined and the sensitive paper; he could then intrust to light the remainder of the work (Fig. 82). Here was just such an epoch-making feat as the intentional kindling of a blaze, or the deliberate rubbing of amber to educe electricity; power of a new order began to spread its vistas to the eye and the mind of man.

Fig. 82.
Maple leaf outlined on sensitive paper.

One stumbling-block at the very outset of the process threatened to be fatal: no sooner was the protected part of the paper withdrawn from the shadow of the object laid upon it to be copied than the light proceeded to blacken every portion of the surface not black already. Light created a picture, and at once wrought its ruin. The obvious need was a solvent for the silver compound which

The Outlines are Detained.

remained unchanged in the part of the paper protected from the light, so that the silver might thence be removed, leaving the light no opportunity to do harm. With such aid from the chemist an unchangeable image of the thing copied would be left behind. In this emergency Fox-Talbot was fortunate enough to discover that a strong solution of common salt was effectual. But a solvent much to be preferred to sodium chloride is sodium thiosulphite, first used by Sir John Herschel in 1839, although he had ascertained its powers twenty years before, —when it was called sodium hyposulphite, a name which the compound still commonly bears. Notwithstanding many an attempt to replace it, sodium thiosulphite meets the needs of fixation to-day as it did when first he employed it. With assured touch and new confidence our copyists then reproduced engravings, etchings, manuscripts, attaining successes which made them bolder still. They learned much by the way concerning the best periods for exposure, the soundest methods for fixing and toning prints, the care and cleanliness inexorable even for the rudiments of photographic manipulation.[1]

But copying by contact is a narrow business, after all, and its adepts soon grew tired of it. Why should not light be impressed into taking pictures directly from the face of nature herself? To every question its answer. At this juncture there arrived a reinforcement from a quarter remote indeed from the chemist's laboratory. Ever since

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[1] In remarkable contrast with the first mode of photographic copying is the "absorption" method shown by Mr. J. Hort Player at the Royal Photographic Society's exhibition, London, September, 1899. This method is to place an etching, a mezzotint, a picture, or document of any kind with its face *uppermost*, and lay upon it in close contact the sensitive surface of a piece of bromide paper subjected to yellow or green light. On development this furnishes a negative from which prints are obtained in the usual way. Surely it can only have been by the rarest instinct for experiment that the discoverer came upon so unforeseeable an effect as this.

The Photographic Camera is Invented.

keyholes have admitted sunbeams into porches, lobbies, and rooms otherwise dark, they have projected images of surrounding scenery, of the panorama of passing life, full of charm and beauty. To Giambattista della Porta, who lived in Italy three centuries ago, these images were no idle marvel; they said, Repeat the construction of this dark room, only make it smaller so that it may be easily carried about, and sharpen its pictures by putting lenses in the aperture through which your light streams in. When Porta had done all this he had made the camera obscura, an instrument popular from his day almost down to our own with scene-painters and other artists who wished either to portray a striking bit of landscape, or to enrich their portfolios with vignettes for ideal compositions. We can well imagine these men toiling at outline and tint, shadow and shade, devoutly wishing for some plan by which they might secure once for all the delicate hues, the refined half-tones, so elusive to pencil and brush. Their longing was to be fulfilled, but only after many days.

Fortunately there was a pioneer in breaking away from mere copying by contact, an experimenter of genius, who was at once familiar with the camera and its images, and with the chemical effects of the solar ray. His predecessors had availed themselves of the alterations of colour which accompany the chemical changes due to an impinging beam of light. He proceeded upon a different and quite original path. He ascertained—it is not known how—that exposure to light effected a remarkable change in the solubility of asphalt, a film of which kept in the dark was as easily dissolved in essential oils as common salt in water, but after a few hours' exposure to sunshine resisted the action of these oils as stoutly as so much stone. In 1816, in an hour momentous for human art, Nicéphore Niépce placed an asphalt plate within a camera, and photography—as we know it—began. The film having been "exposed," then removed from the camera and bathed in oil, showed a clear and beautiful image in low relief.

The structure and office of the eye had now been imitated in such wise as to extend vision far beyond the narrow horizons of sight. Mark the fidelity of the imitation: the eye has its lid, the camera lenses their cap; the iris of the operator is repeated in his diaphragm; the aqueous and vitreous humours of the eye-ball so complement each other in their qualities of refraction and dispersion as to be achromatic, and, thanks to Dollond, a like result follows the combination of crown- and flint-glass in the lenses. Physiologists, indeed, are persuaded that when we see an object, the impression is due to a succession of evanescent images formed so rapidly upon the retina as to seem one picture; the silvered plate of modern photography is therefore deemed only a retina having an impressibility which is lasting instead of transient. What, then, is invention in its furthest reaches but imitation? It is only by faithfully following the footprints of nature that the inventor attains the point where he traces them no more, beyond which the scientific imagination is his only guide.

It was in the combination of two lines of experiment, each of them of a high order, that Niépce stood forth as one of the greatest inventors of all time. He united his camera with a sensitive plate for a fruitfulness almost worthy to rank with that which has followed upon the achievement of Volta, or upon the deed of the hero who first made fire his bond-servant. Sight, thanks to Niépce, now came to its final supersedure of touch. There was a time in the earliest history of the globe when touch was the one sense which distinguished organic life; the amœba remains to tell us how simple that life was. In fresh-water ponds and ditches the microscope reveals this animalcule—which stands lowest on the ladder of life. Destitute of sight, it thrusts out its finger-like projections for food—which it absorbs rather than digests (Fig. 83). Perchance, beginning with creatures as humble as this, light slowly created the eye, so that at last animals could know about external things without having to touch them. Contrast such an animal, however lowly, with the amœba possessed of the single sense of touch, and note the incalculable advantage of being able to detect food, or enemies, or discern shelter, beyond the range of mere contact. No small part of the gulf between man and amœba consists in man being able to know infinitely more through his eye than by his hand. Sight presents him with an illimitable universe instead of the little world in which the fingers of the blind cautiously grope. Vision, it is highly probable, began with the simple power to discriminate light from darkness, this passing into ability to discern outlines, then the forms within these outlines with more and more distinctness; next the estimation of distances might follow, with, possibly, a slow but constant increase in the perception of colours. A development which demanded ages in the case of the eye, was repeated in but a few years as that artificial eye, the camera, parted with one imperfection after another, and came at last not only to equal almost every power of vision, but to attain a responsiveness to rays that fall upon the retina as idly as upon a stone.

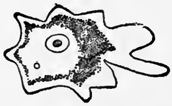

Fig. 83.
Amœba, much enlarged.

The human hand has had no higher office than to depict what the eye can see; that service was to rise to a plane loftier still on the memorable day when, at the bidding of Niépce, it obliged light to print its own images, to be limner as well as revealer. Uncounted ages stand between the savage who first streaked himself with woad or ochre, and the artist who to-day sketches a landscape with his pencil, or paints a portrait with his brush. When once man saw the feasibility of deputing the labour of representation to a beam of light his progress was rapid; in less than a century he has virtually perfected his art, and in many tasks of simple depiction has as far surpassed the scope of brush and pencil as these reach beyond the scrawls and smearings of the cave-dweller.

The Partnership of Daguerre.

Niépce, in 1829, entered into partnership with Daguerre, a scene-painter who had attempted in an original way to fix the beautiful pictures of the camera obscura. Beginning with the use of the resin obtained in distilling the essence of lavender, he had discovered that a silvered plate sensitised with iodine vapour could be impressed by a luminous image. By a happy accident, such as befalls only him who deserves it,—because he has the gift of interpretation,—Daguerre one night left in a cupboard an impressed silver plate. Next morning he was delighted to find that its image had risen to full visibility. Looking about for the cause of this good fortune, he noticed a dish of mercury on the shelf where the plate had stood. He at once suspected the mercury to be the "developer," for he knew that even at ordinary temperatures this metal gives off vapour. A simple test confirmed his suspicion; there and then was established the photographic art of "development," an art with generous rewards for taste as well as skill.

Development as the work of heat was known long before the time of Daguerre. The chemists of the middle ages were ingenious enough to make an ink which stained the paper no more than water as it left the pen; on warming the inscribed tablet before a flame its secret message sprang into full legibility. In a mode much more difficult to follow, light has effects of the same kind. It often works a chemical change unaccompanied by alteration of hue, but let the photographed surface be bathed in the

PLATE VII.

JOSEPH NICEPHORE NIÉPCE.

right developer, and a further rearrangement of molecules sets in, this time with so marked a change of colour that an image emerges to view. A sketcher cannot delegate to any other hand than his own a single line or stipple of his drawing; the whole task is strictly and personally his own. In the fact that the development of a negative may be intrusted to other hands than those which seize an impression there enters a facility wholly new in representation. Its work now falls into that division of labour which has so much economised effort in other fields of toil. In many cases the task of development requires less skill than the taking of a picture, and in all cases it can be pursued at leisure and without the difficulties of place as well as time which may so severely harass the photographer afield.

From its foundation the photographic art has kept in the main to two distinct paths. The one was pioneered by Niépce, whose plate coated with asphalt was hardened by the touch of light, so that a solvent left behind it an image in low relief. The second path, due to Wedgwood and Fox-Talbot, avails itself of the changes of colour wrought by light as it rearranges a chemical compound. In the roll of photographic honour Fox-Talbot takes rank immediately next to Niépce and Daguerre. To him we owe a refinement which effected the first notable reduction in the time required for photography. He immersed his paper in a solution of common salt, and then on one side of the sheet applied a solution of silver nitrate. This resulted in the formation of a silver chloride much more expeditious in its action than those salts formed as the nitrate combines with the sizing of the paper. In respect to beauty, the pictures of Daguerre and Fox-Talbot remain to show us how an art may spring in a single bound to admirable qualities. Yet, after the first flush of enthusiasm regarding the new solar pictures, there succeeded inevitable and just criticism of their defects.

CHAPTER XX

TRUTH OF FORM—THE TRANSLATION AND REPRODUCTION OF COLOUR

Accuracy of Form.

THE lenses of the first cameras were guilty of serious distortions of form: the image of a cube seemed the portrait of a warped and shrunken cake of soap; the protruding hands and feet of a sitter were exaggerated to gigantic proportions. A succession of mathematicians and masters of optics, from Petzval to Ross, Zeiss, and Goerz, have so improved the curves of these lenses, so spaced them apart, so balanced their divergencies in refractive and dispersive quality, as to leave nothing to be desired that is feasible with respect to form. Substance as well as shape has profitably engaged a band of investigators of whom the chief is Dr. Schott of Jena. His first trials were in adding barium silicate to the usual ingredients of glass, importing a refractive and dispersive power new in the glass-maker's art, and producing a very flat field with sharp definition. From among the combinations of lenses now offered the artist and the amateur, they may choose apparatus suited to portraiture, to interior views, or to landscapes, confident of approaching truth in their results so closely that the divergence from it is imperceptible.[1]

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[1] R. S. Cole's *Treatise on Photographic Optics*, London and New York, 1899, is an authoritative work, fully illustrated, and giving mathematical formulæ.

PLATE VIII.

LOUIS JACQUES MANDÉ DAGUERRE.

Retouched from an injured original daguerreotype in the U. S. National Museum, Washington.

The camera itself has undergone improvement not less remarkable than the rectification of its lenses. In its first estate it was so heavy and delicate as to be moved with difficulty and risk. With rare exceptions, its objects had to be brought before it, with serious restrictions of range. The first successful camera in light and portable form was devised by Mr. Kinnear, an English amateur. The popular instruments of the bellows and folding types are derived from apparatus invented by Mr. W. J. Stillman, in 1867. It is because the camera, whether portable or not, has the utmost possible precision that we find it united with the telescope, the spectroscope, and the microscope, with the happiest issue, as we shall shortly see. A camera with accurate lenses not only enables an operator to perform old tasks with unwonted facility: it confers upon him powers wholly new. Let us begin by noting his novel production of the illusion of relief, and then pass to the camera's facility in changing the proportions of a picture.

The Illusion of Relief.

The stereoscope is the child of accurate photography. Provided with two views which have the same slight difference as those received by the two eyes of an observer, it fuses them with the perfect semblance of solidity. The "Laocoon" and the "Apollo" of the Vatican, the sublime ellipse of the Colosseum, the quaint thoroughfares of Siena, Avignon, and Toledo, return to the traveller's eye in vivid relief as he sits in his arm-chair at home and turns the axle of a stereoscope. Very few painters can put upon their canvases the suggestion of solidity offered by these simple pictures. To ask such illusion at the hands of a draughtsman were vain. Through the camera a unique bridge is here thrown between graphic and plastic art. As if by magic, a flat piece of paper rises to the three dimensions of life, and simulates admirably the masterpieces of a Phidias, a Michelangelo, a Thorwaldsen.

Dimensions Easily Varied.

Because its images may be considerably enlarged without blurring, or loss of detail, photography bestows a new resource upon both science and art. Slides of a size that may be readily slipped into the pocket, and much too minute in their details for execution by the pencil, bear pictures which survive in precision the exaggerations of the stereopticon, and play no minor part in the instruction and entertainment of the time. To cite a noteworthy case: every winter the great hall of the American Museum of Natural History, in New York, is thronged with audiences attracted by illustrated recitals of travel, of exploration, of recent advances in science. A series of these lectures of particular importance is conducted by the Department of Public Instruction of the State of New York, and is directed by Professor A. S. Bickmore. Here many of the lecturers are men of science who take part in expeditions for the express purpose of informing their audiences about the most interesting regions of their own country and of the world. Because photographic duplication is a matter of but trifling expense, these lectures are repeated in more than fourscore towns and cities of the United States and Canada, chiefly, of course, in the State of New York. Every considerable museum on the globe, whether of geology, natural history, or fine art, now pieces out the story of its specimens with a collection of sterling photographs. On occasion these furnish slides for the stereopticon as a means of illustration impossible before to-day.

Not seldom the bold enlargements of the lantern effect a brilliant revelation. Hermann Grimm, in the *Deutsche Rundschau* for June, 1893, gave an account of the wonderful effects elicited by the stereopticon as a means of teaching the history of art. No other form of reproduction seems to him so well qualified to bring out the essential features of a great painting or etching as this. Permitting

The Lantern as a Revealer.

one, as it does, to enhance the proportions of a work at will, it brings every line under the closest scrutiny, and thus renders to the student the service which the naturalist derives from the microscope. But in some cases the aid of the stereopticon goes yet further. Some works of art, which in the artist's imagination were conceived in colossal dimensions, he was prevented from carrying out in their appropriate grandeur. Upon these the lantern confers their true proportions. Grimm illustrates this in a conclusive way by an analysis of the principal works of Dürer, Holbein, and Rembrandt. Dürer's "Knight, Death, and Devil," for instance, is known to us through an engraving a few inches in height. This Grimm threw upon the screen, and at once it loomed up before him in such overwhelming statuesqueness that it was perfectly clear that here was the form in which Dürer's mind originally harboured the conception, to execute which in its adequate dimensions he found, however, no opportunity. When, in like manner, the "Passion," the "Apocalyptic Visions," and the "Adoration of the Trinity" were cast upon the screen, they seemed to expand and blossom out into fuller life. The work last named at once took its place by the side of Raphael's "Disputa." Grimm says: "It was a new experience for me thus to see Dürer's works at once enlarged and simplified. The master stood before me as one redeemed. It seemed to me as though his pictures for centuries had been held in prison, and were only now freed and permitted to appear what they really are."[1]

With lenses reversed the precision of photography bestows another, if less striking, benefit upon the artist. We

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[1] *The Little Passion* of Albert Dürer, with an introduction by Austin Dobson, was published by George Bell & Sons, London, 1894. Its reproductions might all be enlarged with the effect remarked by Hermann Grimm.

Pictures in Miniature.

have only to hold an opera-glass wrong end to the eye at a theatre to see the roughly executed scenery take on all the delicacy of a miniature. On this helpful principle an illustrator dashes off a sketch in wash or crayon on a sheet of large size, leaving the camera to reduce and refine his broad effects for the printing-block. Both the illustrations and the manuscripts of the Century Dictionary were brought by photography to microscopical proportions in order that copies might be sent to three separate depositories as a safeguard in case of fire. Another dictionary, originally printed in large type, has been cheaply reproduced in editions of less ample form by means of the camera, dispensing with the services of both compositor and proof-reader. Ever since the days of Solomon it has been lamented that of making books there is no end. With a diminution to a diameter of $\frac{1}{2000}$, and correspondingly to an area of $\frac{1}{4,000,000}$, it would be easy to carry away the National Library at Washington in one small volume. This reducing power of photographic lenses has had ingenious applications in war. During the siege of Paris in 1871, the London *Times* published every day a page of advertisements and news for residents of the beleaguered city. This page, contracted by photography to a diameter of one eight-hundredth part, printed upon tissue-paper, and rolled within a quill, was intrusted to carrier-pigeons. On their arrival in Paris an enlarging camera brought once more to legibility the messages of the newspaper.

The applications of the camera to the microscope have been remarkably gainful. When, however, the magnifications exceed 1000 diameters the production of satisfactory photographs has always been a matter of some difficulty. Mr. J. E. Barnard and Mr. T. A. B. Carver have succeeded in producing photomicrographs up to 5000 diameters by using a simple form of hand-fed arc-lamp. Its intense light has two pre-eminent advantages: it proceeds from a surface so small as to be virtually a point, and from this surface the rays stream forth in a perfectly even illumination. A brief account of this happy alliance of electrical and photographic devices appeared in *Nature*, Vol. LVII, p. 449. It is accompanied by two illustrations, in neither of which is there the slightest decentration so common when the oxyhydrogen light is employed. With moderate magnification and a quick plate, more than one investigator has revealed the inner structure of snow crystals, with hints for the study of other crystals easily deposited from various solutions.

Application to the Microscope.

In addition to its distortions of outline the early photograph suffered from another grave fault—untruth in its interpretation of colour. The violets of a nosegay were as if white, the buttercups and geraniums quite as decidedly black. A good engraver, like Miller, when he interprets in black and white a canvas by Turner, takes pains to preserve the values of the colours, and suggests to the best of his ability the hues of the palette in the lines of his burin. The various colours of the spectrum affect the fibrils of the retina very differently from their action on the silver salts first used in photography. If the chemical theory of vision be true, the retinal surface is built up of compounds remote indeed in character from those which were originally used by Daguerre, Fox-Talbot, and their confrères. Red and violet rays, as they enter the eye, have much the same activity, and yield sensations differing but little in strength. But as long ago as 1777, Scheele, a Swedish chemist, found that violet light has eighty times more effect upon silver chloride than red rays. The photographer, therefore, was loudly bidden so to vary and

Translation of Colour into Black and White.

modify his chemicals as to reduce, or even abolish, the immense disparity between his eye and his plate in their responsiveness to the gamut of colour. In this difficult enterprise, as often before and since, the flower success grew from what appeared to be a seed of failure.

A Lesson from Failure.

When an unreflecting man finds an undesired property in the thing he works with, he simply casts that thing aside and thinks no more about it. To an inventive mind this very property may suggest a new use for which a substance, faulty in its first application, may be exactly suited, and the new utility may far overshadow the service required at first. When dyes from coal-tar, Peruvian bark, and oils began to be manufactured, they had a provoking way of fading out of their fabrics in a few days, or, under strong sunshine, even in a few hours. Usually, too, the more brilliant the tints, the more fleeting they proved. Their evanescence has been in large measure overcome, but before it yielded to the resources of research, a remarkable series of experiments took place; for what is fading in sunshine but a plain advertisement of photographic quality—a susceptibility to change of colour under the impact of light?

In 1873 Dr. H. W. Vogel of Berlin observed that certain of his photographic plates had much more than ordinary sensitiveness to green rays, and he remarked that they were somewhat reddish in hue. Could it be possible that this accident of colour had given his films a new and most desirable sensibility? He at once procured some of the most fugitive dyes he could get chinoline and pyridine dyes, red, violet, and blue. He found, to his delight, that they entered into chemical combination with the salts of silver, conferring upon his plates a greatly heightened susceptibility to rays which before had scarcely wrought any effect at all. A plate tinged with cyanin, a beautiful blue

PLATE IX.

RED ROSE, YELLOW TULIP, AND VIOLETS PHOTOGRAPHED ON AN ORDINARY PLATE.

THE SAME ON AN ORTHOCHROMATIC PLATE.

dye, had surpassing sensitiveness to orange rays; stained with corallin, a compound red in colour, it took on in addition a high impressibility to greenish light. Each dye, let us note, rendered the plate responsive to the rays it absorbed—always complementary to the rays it reflected to the eye.

Provided with an orthochromatic film, manufactured according to the Vogel method, a photographer may now take a picture of a variegated parterre, of October woods, of a lady in richly coloured costume, with a near approach to truth of interpretation. Despite the plate's improvement drawn from dyes, it may still continue to be too impressible by blue and violet rays. The remedy here is also due to Dr. Vogel, to whom the value of a red pane in the window of a "dark room" had long been familiar in its interception of the intensely active blue and violet rays. In one of his early experiments he placed a dark-blue ribbon on a piece of yellow silk; interposing a yellow screen between these objects and the camera, he obtained a picture in which the ribbon was dark and the silk was light—just as they appeared to the eye. To-day screens are manufactured in a wide variety of tones; they cut off the over-active rays during part of an exposure; then, for a moment, the screen is taken away and the blue and violet rays are at full liberty to imprint themselves. The orthochromatic plate is of particular value when gas- or candle-light is employed—comparatively poor in the more active luminous rays. The dyes at present used in the preparation of orthochromatic plates are chiefly eosin, cyanin, azulin, erythrosin, azaleine, and croculein. Botany as well as chemistry has brought its sensitisers to the camera: solutions of the plantain and the blue myrtle have proved their power to correct the colour aberrations of the silver image. Plate IX shows two photographs of a red rose, a yellow tulip, and a few violets; the first photograph was taken with an ordinary plate, the second with an orthochromatic plate.

Aids to Art Study.

An oil-painting photographed on an ordinary plate is like a badly translated poem; but little of its beauty survives: but on an orthochromatic plate the rendition is so just that for the first time in the history of art it is possible to compare the masterpieces of the great painters. To-day a connoisseur places side by side in his cabinet a series of copies of Raphael, Velasquez, Titian, and Rubens, and, almost as if the original canvases were assembled under his eye, he is able to trace the development of each master's successive styles and understand the breadth as well as the distinction of his genius. For the great artists of Venice, Titian, Tintoretto, Carpaccio, and Gentile Bellini, whose works depend much more upon colour than line, the orthochromatic photograph is the first and, indeed, the only adequate reproduction. The most noteworthy photographer in this field is Mr. Domenico Anderson of Rome. "Part of his extraordinary success," says Mr. Bernhard Berenson, "comes from the fact that he always develops and prints his pictures himself, and, having a good artistic memory, he is able to bring out in them, by careful exposure, just the tone that best recalls the original." Reviewing the whole effect of such photography as this upon the data and the judgment of the connoisseur, Mr. Berenson adds: "Printing itself could have had scarcely a greater effect on the study of the classics than photography is beginning to have on the study of the old masters."

Aid to the Astronomer.

In a field far removed from that of fine art, the orthochromatic plate has peculiar value to the astronomer. In seizing the light from coloured stars in the telescope, and in catching the hues of stellar spectra, it has notably advanced his studies of the heavens. It is not, however, in any direct issue, but in affording an indirect means of reproducing colour, that the addition of dyes to silver salts bears its richest fruit.

Colour Photography.

In the ordinary printing of a coloured picture there is a metal block or a lithographic stone for every hue. A picture, if highly variegated, may require as many as twenty different blocks or stones, as it passes through the press, each imparting ink of a particular colour to the printed sheet. The modern analysts of light, beginning with Dr. Thomas Young, have pointed a way to a simpler method. He demonstrated, in 1802, that all the phenomena of colour may be explained by supposing that the retina contains three orders of nerves, each sensitive to waves of a certain length, that is, to a particular colour—red, yellowish green, or violet. He assumed that all other colours may be recognised by exciting these nerves unequally. His theory received full confirmation at the hands of Professor Helmholtz, equally great as an investigator in physics and in physiology. To Professor J. Clerk-Maxwell is due the suggestion that three plates, each inked with a fundamental colour, might replace the multiple series of the chromolithographer.

From among the many attacks upon the intricate problem of reproducing colours by photography, as based upon the three-colour process, it may suffice to choose two fairly typical examples—the first the method of composite heliochromy, devised by Mr. F. E. Ives of Philadelphia. With a camera of his own invention he takes three stereoscopic pairs of images, similar in appearance to ordinary uncoloured lantern-slides, but which, by differences in their light and shade, represent the proportionate distribution of the respective three primary colours in the object photographed. The three negatives are usually taken on a single plate at one exposure. The positive is made by contact-printing in the usual way; the glass plate is then cut in three and mounted on a special hinged frame, designed to bring the respective pairs of images into position in the krōmskōp ("krōmskōp" is "chromoscope" phoneticised). In the daytime the krōmskōp is used in front of a window illuminated by the light of the sky. At night, or where light from the sky is not available, two Welsbach burners, suitably arranged, are employed.

The construction of the krōmskōp is outlined in Fig. 84. *A*, *B*, and *C* are red, blue, and green glasses, against which the corresponding images of the colour record are placed. *D* and *E* are transparent reflectors of coloured glass. *F* represents the eye-lenses for magnifying the image. Beyond *C* is a reflector for illuminating the images at *C*—those at *A* and *B* being illuminated by direct light from above. The operation of the instrument is as follows: The green images are seen directly, in their position at *C*, through the transparent glasses *D* and *E*. The blue images are seen by reflection from the surface of the glass *E*, which makes them appear to occupy the same position, and in fact to become part of the images at *C*. In the same way the red images are seen by reflection from the surface of the glass *D*, and also appear to form part of the images

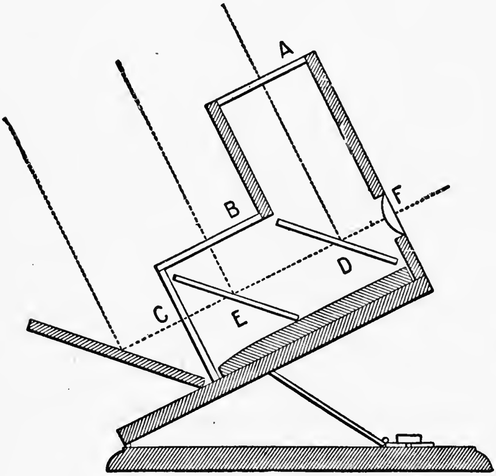

Fig. 84.
Ives's Krōmskōp.

at *C*. And finally, the eye-lenses at *F* not only magnify, but cause the eyes to blend the two images which constitute the complete stereoscopic pair, as in the ordinary stereoscope. The result is a single image, in solid relief, with the closest approach to natural colours yet attained by art. In an ordinary photograph we plainly see that the gamut of light and shade is much narrower than in nature,—the picture is relatively too flat in the high lights, and wanting in detail in the deep shadows,—and for this defect the eye learns to make due allowance. The same fault extends to the Ives picture: its colours at times appear somewhat bleached out in the lighter shades, and seem too dull in the shadows. This defect is not noticeable in some reproductions, but seriously detracts from the beauty of others. An ordinary stereoscopic picture, with its lack of colour, looks more like a clay model than anything else. Endowed with the hues of the krōmskōp, it stands forth with an actuality that marks the highest reach of photographic skill. Mr. Ives has invented a lantern for the projection upon a screen of his three images, which combine with exquisite effect both in colour and in the illusion of relief.

The printer's method is distinct from that of Mr. Ives. Three plates, each prepared so as to respond to a single fundamental hue, are in turn exposed to a camera's image of a coloured object, and from each negative a positive is produced in the ordinary way, and forms a plate to be inked in the press with a pigment of fundamental colour. It is in obtaining pure and appropriate pigments that the printer meets with his chief difficulty; often a particular enamel, rug, tapestry, or oil-painting is reproduced with a happy approximation to truth, and then the next attempt proves a failure because the combination of tints is not well matched in the printing of the three inks. It is worth noticing, as we pass, that in some three-colour processes the hues chosen are red, yellow, and violet-blue—yellow taking the place of the green selected by Young and Helmholtz. With whatever choice of colours, this is assuredly a roundabout way of making a rainbow paint itself, but the direct transcriptions of colour due to Becquerel and Lippmann, admirable as they are, have all the limitations of the daguerreotype—they do not lend themselves to duplication.

The most satisfactory means of laying hold of colour, as well as of translating it into black and white, seems to lie in the adoption of dyes once worthless from their fugitive quality. When German chemists a few years ago sought to dye silk and wool permanently with certain coal-tar compounds, was it not a piece of rare good fortune that they failed? When the first silver plate all too eagerly yielded to the violet ray, preferring it so much to its companion rays, there was exasperation for the printer in black and white, but there was hope for the artist who would recall the tints of the autumn woods, the procession of the flowers, the molten gold of the gates of sunset. This too active violet ray provoked the photographer into making plates with sensitiveness in better balance, and from them are directly descended the plates responsive to but one primary colour. Limitations mechanical and other attend the successful execution of three-colour illustration; perhaps its best example has been reached in the pictures of Dr. W. J. Holland's *Butterfly Book*, where textures as well as tints have been rendered with rare fidelity.[1] Plate I (*frontispiece*) has been borrowed from that book. Such works are now issued at one-fourth the price that was common before the chemist, the electrician, and the printer enabled the photographer to offer tint as well as form in the offspring of his art.

If limning by indirection were ever to be accomplished, the eye of artifice had to see a thing as it is, without warp

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[1] Published by the Doubleday & McClure Company, New York, 1899.

or wryness. This duly attained, it was next needful to bring the photographic plate to the same responsiveness, colour for colour, as that of the retina whose office it would rival. This, too, was done, with the singular outcome that not only does the pencil of the sketcher and the draughtsman know a competitor, but so also does the brush of the painter, notwithstanding the variegation of his palette.

CHAPTER XXI

SWIFTNESS AND ADAPTABILITY—THE DRY PLATE—A NEW WORLD CONQUERED

Time Reductions.

THE first photographs not only left much to be desired in recalling form and colour, but made undue demands upon time. For the impressions shown by Niépce to the Royal Society in 1827, exposures of six hours were necessary. This was much longer than an artist with his pencil or brush would have required. Daguerre, twelve years later, reduced the time demanded to thirty minutes; yet this improvement did not permit him to pass from landscapes to portraits, and at first he did not deem his process suited to portraiture at all. It was Dr. John William Draper who first took a portrait with a camera—that of his sister, Miss Dorothy Catherine Draper—accomplishing the feat early in 1840, at the University of the City of New York, in Washington Square (Plate X). The lady is still living to show us that one long life may bridge the interval between the germination and the flowering of a great art.

Fox-Talbot, taking another tack from that of Niépce and Daguerre, sought to obtain pictures on paper instead of on metal; and paper, because translucent, lent itself to reproduction as "negatives." He made the capital discovery that gallic acid produces upon the salts of silver, when slightly heated, precisely the same blackening effect

Plate X.

COPY OF THE EARLIEST SUNLIGHT PICTURE OF A HUMAN FACE.

Miss Dorothy Catherine Draper, taken by her brother, Professor John William Draper, early in 1840.

as does light. Using this acid as a developer, he was able to shorten the exposure needed for his "calotype" to three minutes. To this day the derivatives of gallic acid maintain their value in the developing-room, against the rivalry of many new compounds.

The next step forward was taken by St. Victor, a nephew of Niépce, who employed glass as a support instead of paper or metal, coating it with a thin layer of sensitised albumen. He thus effected not only a shortening of time, but a gain in convenience and adaptability which revolutionised the art of photography. The transparency of glass gives one a negative incomparably superior to that of any merely translucent material. Keeping to the path broken by Daguerre, John Frederick Goddard, in 1840, exposed an iodised silver plate to the vapour of bromine. He was able forthwith to take an impression upon it in twenty seconds—the greatest feat in time reduction attained by any early inventor in photography. To Le Gray and Scott Archer are due the supplanting of albumen by collodion films, which gave results of new delicacy and beauty. By 1854 the collodion process had driven every other from the field and brought down the time limit to ten seconds. The preparation of these films required two distinct operations—first, the flowing of a glass plate with collodion usually containing ammonium iodide, cadmium iodide, and cadmium bromide; second, the bathing this plate, when it had set, in a solution of silver nitrate, that it might be sensitised. In 1864 Bolton and Sayce abolished the troublesome silver-nitrate bath by combining the sensitive silver salts with the collodion in its original manufacture. The rapidity of these plates was not, however, remarkable.

With every successive shortening of exposure the range of the camera grew broader, portraiture became an amusement for amateurs, and the professional operator no longer dreaded such an annoyance as the blur due to a bud's unfolding while painting itself upon a slow plate. Armed with his collodion films, the photographer paused as if he had reached the summit of his art. He was really but crossing a temporary bridge. Among the photographers who refused to rest and be thankful was Dr. R. L. Maddox of Southampton, in England, whose objections to collodion plates were manifold. Their preparation, he said, was costly, slow, and hazardous; because they had to be used wet, they demanded the services of a skilled operator, while they were restricted to such brief impressions as might be received before the plate dried. With a view to finding something less troublesome than collodion, Dr. Maddox began a series of experiments with isinglass. Dissatisfied with its results, he turned to gelatin, uniting with it silver iodide such as he had been accustomed to combine with collodion. Just then he had been photographing some laurels, and had made a rather poor picture. What could improve his imperfect plate? He remembered having heard that for foliage the bromides of silver are better suited than the iodides. To the bromides he forthwith resorted, increasing the quantity by degrees, and lessening that of the iodides. So marked at that point was his success that he decided to use the bromides alone, achieving results still more satisfactory.

The Gelatin Dry Plate.

When, in 1871, the first effective dry gelatin plate thus saw the light of day and took its impress, Dr. Maddox at once published his experiments. To some of the leaders in photography, professional and amateur, their promise was as clear as that of dawn. Mr. Charles Bennett of London, by warming the gelatin emulsion for days together brought it to a sensitiveness and permanence which made it straightway a commercial as well as an artistic success. In 1879 Mansfield brought the emulsion to the temperature of boiling water, and found that in less than an hour it had acquired the maximum of sensitive quality. A collodion wet plate demands an exposure of from ten to fifteen seconds; a dry plate does its work in a tenth, a thousandth, or even a smaller fraction of a second. And yet collodion, from its finer texture, is capable of effects so delicate as to make the critic hope that its best qualities may yet be imported into a dry plate as rapid as that to-day composed of gelatin. In a narrow range of important work, chiefly in the manufacture of printers' plates, collodion emulsions are still indispensable; in nearly every other department of photography their rival holds the field. As we note the successive uses of the dry plate, and observe how vastly it enlarges the scope of the camera, we shall see how eminent a place Dr. Maddox occupies among the great inventors who have made photography what it is.

Control of the Time Limit.

Beginning with a time limit of one second, the dry gelatin plate has been so increased in sensitiveness that M. L. Decombe, of the Paris Academy of Sciences, has employed it to photograph Hertz waves in less than the five-millionth part of a second. A triumph such as this is to be credited to new accelerations in "developing"—an art which reaches the tap-root beneath both physics and chemistry. To-day the photographer in the wide diversity of his plates, quick and slow, has complete control of the element of time, and his camera consequently enjoys unlimited adaptability. Let us note, too, the advantages of the dry plate as compared with its predecessor. It is always ready for use; it requires no troublesome liquid accessories; it can be placed in any position; it may have a backing, not of brittle glass, but of flexible celluloid; it even dispenses with an operator—an impression may be had by the touch of a spring setting free an automatic mechanism. After an exposure lasting but an instant, or protracted for hours, the plate may be developed at pleasure many months later. Endowed with this wealth of quality, the dry gelatin plate takes rank with the electromagnet, or with the optical lens to which it is itself joined, as one of the creative inventions which not only add to the capital of science and art, but also increase the rate at which its gains are heaped higher and higher. On the threshold of photography it was debated whether a pencil of light could work as rapidly as the pencil of art. By successive advances the camera has all but overcome the tyranny of time, and stretches its sway into dominions where the pencil and brush, however skilfully held, would have remained unexercised forever.

The Dry Plate Afield.

Let us take a rapid glance at the camera, provided with dry plates, in the hands of the man of science afield. Were he restricted to pencil or brush, or even to the wet plates of the collodion process, he would suffer not only great loss of time, he would miss taking ninety-nine pictures out of every hundred that now fill his portfolio. In the whole sphere of ingenuity there is no happier case of initiation than the touch on a kodak that affords an impression which, perhaps a year later, is completed as a picture. It is therefore as plain as its own daylight that, in its most ordinary applications, photography vastly multiplies the winnings of a trained observer; it does all that an accomplished sketcher can do, and does it with unimpeachable accuracy, with a swiftness all but instantaneous. Mark its services to a botanist as he journeys in Colorado, or in the Canadian Northwest. While gathering specimens for his collection, he secures the portrait of a flower here, a shrub there, in the full flush of life, very different from the mummified remains entombed in the herbarium. Once more at home, his slides, coloured to nature, transport metropolitan assemblies to new worlds of floral beauty.

In labours less fascinating, but of higher claim, the student employs photography to compare the tissues of allied plants as diversified at the sea-level and on the mountain-top; as modified by the frosts of Alaska, or by the arid winds of Nevada; or, in an inspection still more intimate, to detect the formation of starch in a leaf as furthered by generous warmth and light. Botany has an economic side which is constantly kept in view. From the Departments of Agriculture at Washington and Ottawa, from experimental farms scattered throughout North America, many thousand seeds, cuttings, and saplings are distributed every year. It may be an apple from Russia, or wheat from Finland, that is portrayed as it grows—with unmistakable evidence of its thrift or failure. When the pictures are compared, much is learned as to the varieties best suited for severe climates, for sandy soils, for the quick production of timber, or a stout resistance to vermin. No pencil sketches could have the same perfect trustworthiness. In combating pests of all kinds, whether fungi, beetles, or flies, new methods are constantly devised, and nothing makes them so easily understood as a photograph. Forestry is to-day receiving a noteworthy impulse at the hands of Mr. Gifford Pinchot, forester of the United States Department of Agriculture at Washington. His bulletins derive attractiveness as well as value from illustrations due to the camera. He has in hand a photographic description of the forests of the United States, which is steadily approaching completion.

To the student of rocks the camera is every whit as useful as to the student of plants. It gives him prints, omitting no detail of dip or strike. It affords memoranda of cuttings and shafts which the engineer may be obliged to cover on the very day of their exposure. In the new education, geology and geography are studied together; the features of the earth, recognised as more than skin-deep, are referred to the world forces age-long in activity whose surface manifestations they are. Accordingly, the geographer, as well as the geologist, seeks to be an adept with the camera. Particularly significant are photographs of the effects wrought by torrential rain, by glacial action, by the rapid erosion due to sand-storms; all of them showing at work to-day the enginery which in the illimitable past has sculptured the earth from primeval chaos. To do this adequately it is necessary to take panoramic views, part by part. A camera is carefully levelled, its first plate is impressed, the camera is then revolved so that a second impression overlaps the first a little, and so on until the whole horizon is traversed.

The land-surveyor, whose relations with the geographer are often those of a partner, especially in the exploration of a new country, has for years used a camera with lenses at once telescopic and photographic. These lenses are of a form which will cover an angular field of 60° without measurable distortion, and give uniform definition all over the plate. The pioneer in this branch of art was M. Beautemps Beaupré, who began his labours more than fifty years ago. In the comparatively recent development of photographic surveying the leaders are Colonel Laussedat, the director of the Conservatory of Arts and Trades in Paris, and Mr. Bridges of London. Thanks to their skill, phototheodolites are now built with power to sweep a radius of four miles and more. In the preliminary surveys for a canal, or railway, the camera is much preferable to ordinary surveying instruments. It is often very difficult to determine beforehand how much mapping will be necessary to give the engineer all the data for a choice among the various routes in his purview. The district may have to be revisited again and again to supply the requisite details, and most of them may prove useless in the end. But if the field has been intelligently photographed

THE JUNGFRAU FROM THE HÖHEWEG, INTERLAKEN, SWITZERLAND (SIXTEEN MILES DISTANT).

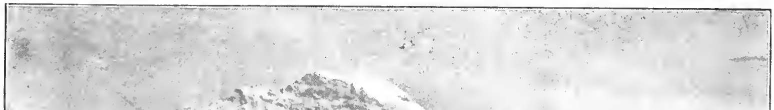

PLATE XI.

From Scribners' Magazine, October, 1899. Copyright, 1899, by Charles Scribner's Sons.

THE JUNGFRAU FROM THE SAME STANDPOINT (SIXTEEN MILES DISTANT), TELEPHOTO LENS.

there is no necessity to return in quest of incidental features.

A noteworthy feat in the photographic survey of new country was accomplished in 1893–94 by M. E. Deville. He succeeded in covering no less than 14,000 square miles of the Rocky Mountain territory of Canada, carrying his camera to the boundary of Alaska, over passes of uncommon difficulty. As the result of careful comparison he estimates that photography is but one-third as expensive as the old method of the plane-table, while much more expeditious. A remarkable map of the Canadian National Park, created by the telescopic camera, was exhibited at the Columbian Exposition in 1893. It was made up of twelve sheets, each comprising a view of about sixty-three square miles in area.

Where mountain-peaks do not afford him an elevated outlook, a surveyor may leave the earth and betake himself to a balloon. In a photograph secured 700 feet above Stamford Hill, in London, the topographical features were defined much more sharply than would have been possible without the camera.

Telephotography, in fields other than that of land-surveying, is now prosecuted with remarkable results. With lenses developed from those of an opera-glass, M. F. Boissonas of Geneva has taken a photograph of Mont Blanc, full of detail, at a distance of forty-four miles. This and many other striking pictures are reproduced by Mr. Thomas R. Dallmeyer in a work which describes one of the most attractive departments of photography.[1] Mr. Dallmeyer shows us how much a telephotographic camera improves ordinary portraiture by its precision of perspective. In many diverse walks of science this camera has an array of tempting gifts: it offers the geologist a minute

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[1] *Telephotography*, by Thomas R. Dallmeyer. London, W. Heineman; New York, Longmans, Green & Co., 1899.

delineation of the stratification of cliffs far beyond the range of common lenses. The architect and the student of archæology can readily secure pictures of carving and sculpture otherwise quite inaccessible, while large buildings may be photographed from such a distance that they will appear virtually as plans in elevation; the naturalist, without alarming a rabbit in its form, or a grebe on its nest, may obtain a portrait of either in a most characteristic attitude. Mr. Dwight L. Elmendorf of New York has pursued this branch of art with uncommon success. Plate XI is reproduced from illustrations which accompanied his article on "Telephotography" in *Scribners' Magazine*, October, 1899.

Since the historic feats of Mr. James Glaisher, in 1862, —which nearly cost him his life,—balloons have added much to the data of meteorology. An elevation of a single mile often reveals strong aerial currents unfelt at the surface of the earth, and which give warning of an approaching storm. But a balloon is costly and hard to manage; for many purposes, even to a height of two miles, a well-built kite is equally serviceable, especially when fitted with appliances both electric and photographic. In the application of kites to answering the questions of the meteorologist, the place of honour is held by Mr. A. Lawrence Rotch, of the Blue Hill Meteorological Observatory, near Boston, Massachusetts.[1]

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[1] Mr. Rotch writes (under date of December 9, 1899): "I have just received my automatic kite-camera from the maker, M. L. Gaumont of Paris. Its design is based upon that of the much larger camera constructed for M. Cailletet in order to photograph from a balloon the ground vertically beneath, so that by reference to a scale-map the height as well as the drift of the balloon might be determined. The present apparatus is intended to photograph the upper surfaces of clouds, and may also serve to make a map of the country over which it passes. As it is intended to be lifted by kites its weight is but six pounds. It is contained in a box about six inches cube, and will be suspended vertically below the balloon. There are three clock movements: the first operates the shutter of the objective; the second controls the operation of view-taking (which is

Photographed by W. E. Carlin of New York.

PIKA, OR LITTLE CHIEF HARE.

PLATE XII. *Copyright by George Shiras, 3rd, 1898.*

DEER PHOTOGRAPHED AT NIGHT.

TYPICAL PHOTOGRAPHS OF LIVE ANIMALS.

Gifts to the Study of Life.

The simplicity and celerity of the camera give it inestimable value to the naturalist or the physiologist. It enables him to follow day by day, even hour by hour, the development of a bacillus, a mollusc, or a chick. He might, if quick and skilful with the pencil, draw a portrait or two for his note-book, but how could he find time and opportunity to sketch a hundred? In exploration it provides him with an instant means of depicting an insect, a reptile, or a bird in its home surroundings—perchance in the very act of seizing its prey. Mr. Cherry Kearton, the English naturalist-photographer, has shown us what prowess joined to skill can do in catching glimpses of sea-birds perched on crags which, to wingless man, are perilous in the extreme. Mr. William E. Carlin of New York, with equal enthusiasm, has secured portraits of the very shyest quadrupeds of the Rockies; his picture of the pika, or little chief hare, is of unexampled rarity (Plate XII). Taking another path, Mr. George Shiras III of Pittsburg has sought out wild deer which, for the most part, feed and drink at night. His photographs, taken by flash-light, are among the best ever added to the portrait-gallery of natural history (Plate XII).

From the Field of Health to the Bedside of Disease.

Physicians find the camera an important means of registering the course of a malady and of studying its treatment, the pictures easily lending themselves, furthermore, to class-room instruction. No student of bacteriology to-day considers himself fully equipped for study until he has reached the mastery of a camera; for his "cultures," microscopic as they are in size, would

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regulated before the camera leaves the ground, the period being intended to vary from ten minutes to two hours); the third is charged with turning the roll of three-inch film. The time between successive exposures may be any period from three to nine minutes."

demand the rarest aptitude to be accurately sketched. At times the instrument may be discarded while its chemicals are retained for direct use. The physiologist, injecting silver salts into nervous tissue, is rewarded by a series of blackened branchings, each telling a hitherto untold story of structure and function.

The camera sees much where the eye sees nothing, because the photographic film is impressible by many kinds of light that are without effect on the retina. In Ohio, a few years ago, a lawsuit was decided when the fifth signature to a will, otherwise undecipherable, came out clearly in a photograph. A skilful use of the same subtile vision brings to light the first inscription committed to ancient parchments—the writing all but completely erased for a second use of the vellum. The gaze of a camera has been turned upon an adult puma, and at once the spots which, to unaided sight, disappeared in its youth, came forth plainly on the sensitive plate. A case of smallpox may in like manner be detected by its blotches showing themselves in a photograph long before they are discernible to the eye.

Aboriginal Portraiture.

It is a curious fact that the improvements which make the camera at once small and speedy in action place a new facility in the hands of the anthropologist—that student of man, not as an assemblage of tissues, but as a bundle of primitive traits, habits, and customs. The informed traveller among the remaining aborigines of the world is anxious about their impending disappearance, not merely by the sword or through disease, but by a semi-civilisation not less fatal to their best traditions in art and industry. From superstitious or other fear, the native in many parts of America, Africa, and Australia has an unconquerable aversion to having his portrait taken. Says Mr. E. F. im Thurn: "Instantaneous and secretly taken photographs are best, as savages are usually afraid to be photographed. A Carib of Guiana, when in Georgetown, looks cowed and miserable; in the country, at home, he is a manly and attractive chap." Photography is doing no worthier work in the world than when it thus catches every surviving relic of savage and barbaric life. That the New-Zealanders are alive to this question of depicting aboriginal art is evident in a note from Mr. A. Hamilton of the University of Otago, Dunedin (dated August 3, 1899): "I am photographing all the carvings and similar relics that remain in New Zealand, and obtaining representations by photography of social arts, such as planting food-crops, weaving, fire-making by friction, and so on. Some of these will be published in my book on *Maori Art*, now in its fourth part, issued at the expense of the New Zealand Institute, Wellington. I am also forming for the institute a record collection of all the photographs that I can get from European and other museums of the Maori articles in their collections."

Whether a savage resembles our ancestors or differs from them, equally instructive is a full portrayal of the man himself, of his response to the needs of sustenance, shelter, and war, his attempts, often admirable, at decoration and the symbolism of religion. We are wont to mourn the species of birds and beasts that have disappeared forever before the sportsman and the plume-seeker. But how much poorer is the world for the loss of such a tribe of men as that which, about a century ago, became extinct on the Easter Islands, leaving behind writing of great beauty as a token of their high rank in art and intelligence! Even from an economic point of view, native industries, such as those of the American Indians, richly repay study. The shawls and blankets, the baskets and pottery, in the National Museum at Washington are not simply a feast for the eye: they have golden hints for the manufacturer.

These aboriginal masterpieces deserve to be accurately reproduced in colours, not only to give delight to the world around, but to enrich the repertory of every thoughtful designer.

The traveller and the explorer, whether they be men of science or not, owe much to the gelatin plate, which defies climatic stresses, however severe. A few years ago it was a matter of great difficulty to secure *en route* good negatives on collodion films. Often when the photographer reached home he found, to his chagrin, that his plates were worthless. To-day Mr. Peary easily obtains excellent pictures in the arctic regions, while scenes in tropical Africa and South America are photographed with equal perfection, their extremes of climate exerting no effect upon the plates employed.

Pictures in Series, and New Revelations.

The ease and quickness of the camera open to it a wide field in picturing the progress of work too rapid or too complicated for the pencil. A large group of constructors—engineers, architects, ship-builders—derive help from the photographs readily taken day by day, which explain in the clearest manner the erection of a bridge, a steel office building, or an armoured cruiser. With the same invaluable aid a landscape-gardener, a forester, or an expert in irrigation, may follow in his city office the prosecution of his various plans nearly as well as if he were supervising a single task, and on the ground in person. In a foundry or a machine-shop the pictures taken during an important casting, or an elaborate piece of engine construction, enable it to be duplicated at any future time, there or elsewhere, with much aid to beginners, with much useful refreshing of memories on the part of their seniors.

The engineer, discarding the pencil for the camera, draws upon the physicist for a gainful loan, with the result that he learns much in the field of design and experiment.

Borrowing his polariser, a simple instrument which brings light to a single plane of vibration, he uses it as a searcher. A change in the inner structure of glass, though due to but moderate pressure, may be detected in altering the refrangibility of a beam of polarised light. The inventor who thinks that he has devised a truss, or a girder, of new efficiency has, therefore, only to construct a model in glass to bring his plan to an inexpensive test. A beam of polarised light sent through the glass will plainly show to the eye, and register in the camera, the distribution and extent of the strains imposed by a moving load. In like manner a piece of glass which has been imperfectly annealed at once declares its weakness, so that it may be excluded from chemical uses or mechanical pressures likely to be too severe for it. The lenses of large telescopes, as moved through wide variations of angle with the horizon, are subjected to severe strains. It is imperative, therefore, that they should be manufactured of thoroughly annealed glass. In the case of the thirty-six-inch telescope at Lick Observatory, nineteen discs of glass as tested by polarised light were rejected before a disc of satisfactory quality was found. The same subtile detective is yielding knowledge of the architecture of crystals, and, passing from the laboratory-table to the counter, it is busy separating false gems from real, and adulterants from food, drugs, and the raw materials of the spinner and the chemist.

Longitude Ascertained.

Aid to the navigator more ingenious still is proffered by Dr. C. Runge, who has much simplified the ascertainment of longitude, commonly a difficult task. He first photographs the moon, then, at intervals, bright stars or planets which come to the place where the moon appeared a few minutes before. From these pictures, accurately timed, the longitude can be computed with readiness from the data of the nautical almanac.

Amateur Illustrations.

While the camera in its highest work may call forth all the mind and skill of a man of the eminence of Captain Abney, or Mr. Matthew Carey Lea, let the ordinary user of it be glad that in its everyday applications it easily falls within the range of his judgment and adroitness. Thanks to the inventors who have simplified its form, reduced its size, improved its films, condensed its chemicals to tablets soluble at pleasure, and produced papers which may be developed in ordinary light, the camera now supplements the pen in a delightful way. A young fellow leaves his home in New York to become a miner in Arizona. He writes to his friends, describing his new surroundings, and this he does graphically and well. But he manages "to take them to the place," as the Scotch say, by a few snap-shots which show his cabin, the shaft in which he toils, the neighbouring cave with its array of stalactites and stalagmites; while the force of the occasional rain-floods from the mountains overhanging the mine is depicted in the utter wreckage of a village street. Or it may be that this young fellow is sufficiently advanced in his fortunes to take a trip to Mexico. His note-book, as well as his letters, are enriched in the most telling way by a camera no bigger than a cartridge-box. The sensitive plate, repeating what it sees, completes the description in words, and henceforth the young miner's friends in the distant East can imagine him just as he is—in a world to them almost as strange as if it were another planet. It is this new power to make others far away both in time and place see all that meets one's eye here and now, and this with the very minimum of skill or outlay, that gives photography a universality denied to the work of the pencil or the brush. To wield these acceptably, no matter what enthusiasts may say, requires both natural aptitude and judicious training. In the transference of impressions the kodak does thoroughly and at once much that before photography demanded uncommon talent, and opportunities for the education of that talent which were rarer still.

When an amateur takes up a congenial field of photography, and patiently cultivates the portraiture of flowers, or birds, or aught else, he soon finds himself a well-informed student without intending it, an authority, perchance, and that in a domain which is certain to grow in its interest as he tills it longer and better. And he may do less than this and still be rewarded. Poor indeed is the holiday jaunt that cannot leave him reminders in picturesque bits of road, of woodland, or of brookside. From the brain a scene begins to fade the moment the eye ceases to rest upon it, but the camera has a memory that never forgets.

If photography brings much of refined pleasure to the amateur, it owes not a little, in turn, to the men who have used the camera simply because they thoroughly liked its work. Some of the most valuable compounds used in photography, some of its best forms of apparatus, are due to the non-professional and non-professorial tenants of the dark-room. To investigators of the philosophical grasp of Mr. Lea and Captain Abney the sensitive plate has been a starting-point for researches in physics, chemistry, and optics, all brought to converge upon the modern triumphs of light as a limner. The supreme advantage of photography as an instructor is that experimental work is its very basis, and that results of some kind or other are always visible.

Pictorial Art.

It is often laid to the charge of the camera that it has dealt drawing a mortal blow—that the free-hand sketch is becoming more and more rare. Yet if the skill of the draughtsman is less in request than of old, it must be admitted that the quality of drawing has distinctly improved under the pitiless rivalry of the photograph. Bad drawing and faulty perspective are tolerated no more, even when a good colourist displays them, for to-day everybody has been educated by the camera to require that creative art, no matter how high it may rise, shall nevertheless be grounded in truth of representation. In so far as the camera has displaced the pencil, where there is time and opportunity for a sketch, the fact is of a piece with the unceasing encroachments of mechanism upon handicraft. Such supersedures make us, in the main, richer; but as new gains are heaped on our panniers they throw to the ground more than one golden heritage.

It is a sound dictum of art that only those who draw ever really see, and if the task of limning is transacted by machinery, much priceless education of the eye, the hand, and the brain is unquestionably missed. Wherever the camera has induced any one to lay down the pencil or the brush, who might have wielded it with power, it has done harm. But it is debatable whether very many souls that have felt the stirrings of creative faculty have ever allowed them to be cramped or stifled by photography. The irrepressible skill of the sketcher is a possession of the few, the deftness of the camerist is for the many.

The camera every day becomes a more and more important means of bringing to the illustrator, the designer, the painter, the sculptor, the elements of their compositions. Beginning with sound and accurate representations of reality, the pencil proceeds to their idealisation, its success turning upon the extent, variety, and truth of the transcripts from nature. Just as a novelist like Scott, a poet like Tennyson, rises to imaginative flights all the more assured and convincing for his close and patient observation of a pebbly beach, a curling breaker, so the eye quick to catch a hint in the ripple of a wave, the whorl of a fern, the trail of a vine, the sunbeam bursting from a cloud, can store a photographic note-book with a thousand

PLATE XIII

THE WEST WIND.

outlines for subsequent elaboration, often when there is neither time nor place for a pencil sketch, however rapid.

Because observed and recorded truth gains ineffable charm when transmuted by the mind and soul of an artist, his works and those of the photographer occupy two distinct worlds. Says Mr. Frederick Crowninshield: "The greater the triumphs of photography over nature, the greater the necessity for the emphasis of the artistic qualities. Photography cannot by its graphic accuracy rout the born artist, who must be just as accurate in the rendering of his soul's images as the sensitive plate is in the glassing of nature's facts." And yet, while the spheres of fine art and of the camera thus remain apart, they touch each other at more points than one. Everybody who has seen the recent photographic exhibitions in Paris, London, and New York is aware that pictorial photography has lately taken a notable stride forward. Fetters that ten years ago seemed of iron rigidity have been relaxed in a remarkable degree. By dint of the widest play of chemical experiment, by locally modifying the developing and printing processes, a new school of camerists have attained results of a value and beauty impossible in the days of the albumen print. The portrait of Charles Darwin by Mrs. Cameron, of Mr. Eickemeyer by his son, of Sir Edward Burne-Jones by Mr. Frederick Hollyer, together with the landscapes of Mr. Alfred Stieglitz and Mr. George Davison, show us the work of artists who have chosen to work with platinum and silver salts, when they might with success have devoted themselves to the pencil and the brush.[1] "The West Wind" (Plate XIII), by Mr. J. Whitall Nicholson of Philadelphia, is an excellent example of a picture created by photography.

[1] Mr. Alfred Stieglitz has an illustrated article on "Pictorial Photography" in *Scribners' Magazine*, November, 1899.

A capital paper on "The Relation of Photography to Art," by Mr. James Craig, appeared in the *Photographic Times*, June, 1899.

Photo-sculpture.

Mr. George G. Rockwood, the well-known photographer of New York, has recently perfected a simple mode of bringing the camera to the aid of a sculptor as he creates a portrait in bas-relief. In a moderately lighted room he prepares a flat slab of clay, upon which is projected from a stereopticon a strongly illuminated portrait—just as in the ordinary illustration of a lecture. With this aid the modeller executes his task at a pace and with a verity of result not otherwise possible. A bas-relief of President McKinley, produced in this way, is life-like.

In co-operation with a friend Mr. Rockwood has arrived at a method of producing small effigies, two inches or less in diameter, employing photography solely from first to last. The degree of relief obtained may be considerably higher than that of the coins of the United States. Any carefully modelled design or drawing may be used, and indeed anything whatever that can be well photographed. This singular and novel art has not yet been disclosed to the public in its details. In its essence it takes advantage of a property for many years invaluable to the camerist—the solubility of bichromated gelatin as affected by exposure to light. This solubility, varying as it does with every degree of illumination from the shadows to the high lights of an image, enables that image to be registered in relief with an effect such as hitherto has been won only by protracted toil with the graver.

The Camera and the Engraver.

As we noted in the last chapter, one of the worthiest tasks which can be assumed by either the amateur or the professional photographer is the reproduction of the masterpieces of fine art. This, not so long ago, was the field of the engraver; to-day his skill is largely in demand, not for engraving, pure and simple, but for an alliance with photography. In a noteworthy case there is no rivalry between the burin and the camera, but instead only co-operation guided by the rarest skill and intelligence. The superb copies of Italian, Dutch, Flemish, and English paintings by Timothy Cole are produced from photographed blocks upon which the colour values are carefully restored; the artist then proceeds to engrave these blocks with the originals before him.

A Handmaiden to Literature.

At many points graphic art and literature join hands. The written like the spoken word, for all its power, has a limited dominion. Words cannot delineate a coast-line or a hill, repeat a sunset, or portray a human face. Photography, the new and universal language, united to words, completes their meaning with the effect that the whole of truth is matched and told as never before. The worthiest fruitage of primitive picturing is undoubtedly the art of writing. Incalculable though the value of writing may be, and of its offspring printing, their characters have lost much in the conventions which make it impossible to detect the likeness of a thing in its name. Professor Scripture of Yale University in a series of tests has found reason to believe that the acquisition of a foreign tongue can be hastened threefold when pictures accompany the words. Comenius, two centuries ago, was one of the first teachers to add pictures to books. For nearly two hundred years the cost of illustration forbade anything but the most infrequent imitation of his example. To-day, thanks to photography, written language resumes its ancient alliance with the picture. Every book the better for illustration is illustrated; while the word spoken by the instructor or the entertainer is as helpfully supplemented by the photographic slide. Among the instruments which give recorded science its new verity, the camera is one of the chief.

The man of letters is an artist whose studio is the library, who works with the pen instead of the brush. He, too, owes a weighty debt to the camera. It gives him, on nominal terms, facsimiles of the rarest printed books in the Bodleian Library at Oxford. In Mr. B. F. Stevens's reproductions of *Manuscripts in European Archives Relating to America*, the foundations of American history are bared at the same moment to hundreds of students scattered throughout the world. The camera, too, convicts the forger of documents, or of manuscripts and books not less valuable, and serves to restore writing otherwise illegible through fading and wear. For contemporary annals the camera is all too generous. It is so prodigal of pictures as to be embarrassing.

With this glance at the services of the camera to art and to letters, let us now turn to the tasks of the expert operator who, in a special field of science, employs plates of uncommon qualities.

CHAPTER XXII

THE WORK OF QUICK PLATES—PHOTOGRAPHIC REPRODUCTION

Vision is Slow.

WHEN one looks out from a fast express train the sign-boards of the way-stations are quite illegible, the impressions formed by their letters are too brief for clear perception. Hence the disposal of generous breadths of flowers, shrubs, or gravel, so as to form "Melrose" or "Spuyten Duyvil" fifty or a hundred yards away from the track, and clearly to be read in the swiftest running by. In nature as well as in art there is a world of motion which far transcends the narrow time limits of the eye's impressibility. Here, as in many another field, the camera enables us to see what otherwise were forever invisible. In the three-thousandth part of a second the sun has taken his own portrait, while the momentary phases of eclipses, solar and lunar, of planetary occultations and transits, have been seized by the dry plate in periods much too short for collodion, and, therefore, vastly too brief for the pencil of the sketcher. Dr. W. L. Elkin of Yale Observatory, by taking simultaneous photographs of meteors with cameras remote from each other, has established their height as being forty-five to sixty-five miles from the earth.

With plates all but instantaneous the operator catches the contour of a bar of maple or steel at the instant of rupture under strain, the details of an explosion, the path of a rocket through the air. Lord Rayleigh, in the feat of photographing a bursting bubble, discovered that its collapse took place in the three-hundredth part of a second. The terrific power of air when rushing along as a tornado or cyclone has surpassed, until modern times, all means of measurement. Air to-day may be observed as it moves at a pace so far surpassing that of a tornado, or a cyclone, as readily to pierce the stoutest steel. From the photographs of air-disturbances caused by flying shot, it seems that the missile never comes into immediate contact with the armour-plate which, nevertheless, is riven asunder. It appears that the hole for the passage of the shot is made by an envelope of air that surrounds the projectile and travels with it. Strangely enough, the splash of the shot as it strikes the steel armour closely resembles the splash of a marble dropped into milk. When nature draws her parallels the lines may be remote enough from each other; and clearly does she teach us here that solids and liquids which seem distinct and apart are not so very different, after all. Given a projectile swift enough and the toughest steel moves before it like so much milk.

The Study of Animal Motion.

The American pioneer in the quick photography of animal motion was Mr. E. Muybridge, whose famous pictures, published by the University of Pennsylvania, portray horses walking and racing, birds in flight, athletes jumping and running. In extreme cases Mr. Muybridge's exposures lasted for only the $\frac{1}{5000}$ of a second. His photographic arrests of movements too swift for the eye have enabled Meissonier in France, and Remington in America, to revise their representations of animal motion—with variously criticised effect. If a visual perception, it is argued, lasts one twenty-fifth of a second, why not match it with a picture secured in a period not any shorter? Then, too, it is added, the brain builds up its impressions of rapid motion from those phases which are frequently repeated. These, therefore, should be more dwelt upon as pictorial elements than phases comparatively rare. To this it may be responded that our notions as to the attitudes of animals fleeing or flying have been largely derived from conventional and untrue pictures, intended rather to please the eye than to inform the mind. As these inherited notions are corrected by the camera, the feeling that its deliverances are ugly wears off as we see that they stand, in part at least, not for inaccurate tradition, but for truth. "Instantaneous" photographs show us that many of the Japanese bronzes of herons and hawks are not grotesques, as was thought by their first European and American admirers, but are due to observation of attitudes too brief for any but the alert and disciplined eye of a Japanese modeller.

Philosophers Re-enter the Nursery.

Within the past few years some of the most eminent men in the ranks of science have returned to the playthings of their childhood, and, at first view, with some danger to their dignity, have begun the serious study of the hoop, the top, the bubble, and the kite. Strange to say, these simple objects have brought them to the limit of their powers, and they confess that much remains to be understood regarding the toys that for ages have amused the youngsters of every clime. A boy four years old may notice that the quicker he trundles his hoop the likelier it is to stay upright, or, a little later in his round of sport, he may remark that the swifter his pace on a bicycle the better assured is his perch. Both, he will duly learn, are cases of the same law. A top in its com plex gyrations, especially in those of its "dying down," requires many lengthy formulæ to express the forces in play.

More intricate still are the impulsions and checks which make the paths of a gyroscope a paradox to everybody but the mathematician. These paths attentively studied are found to explain orbits at the extremes of vastness and minuteness—those of the planets in the sky, those of the particles in a magnet. Children scarcely out of their long clothes manage to blow soap bubbles, and as the films thin out to fatal collapse the physicist gets a hint as to the dimensions of a molecule, or as they belt themselves into mimic rainbows he reads the lengths of waves of light, or employs them to detect minute quantities of electricity. We smile when we hear that grown-up Chinamen amuse themselves at flying kites, but to fly kites as well as they do implies a good deal of uncommon observation. An accomplished kite-flier takes advantage of those upward streams of air that ordinary dwellers upon earth know little about—streams which enable heavy birds to soar without apparent effort. A toy sparrow sold for a dime is propelled with muscles extemporised from a rubber band. Coil this rubber tightly and the bird will rise to a lofty ceiling. Let the scale of this achievement be successfully enlarged and the problem of man's reign in the air is solved forthwith.

Plateau's Toy the Germ of the Kinetoscope.

Nearly a century ago, Plateau, a Belgian physicist of distinction, devised a toy worthy, from its significance as well as its amusing power, to have a place of honour beside the top, the hoop, and the kite. Like every other successful toy, this of Plateau's depends upon motion. In its familiar form his zoetrope, or wheel of life, is a cylinder eight or ten inches in width, about seven inches high, and open at the top. Around the lower half of its interior is a series of pictures showing, let us say, a boy in the successive attitudes of a leap (Fig. 85). These pictures are looked at through narrow slits in the cylinder while it is revolved rapidly. Each visual impression of a picture lasts the twenty-fifth of a second, and before it has time to fade away there is superposed on the retina an impression from the next and but slightly different picture, and so on throughout the series. Because the impressions blend with one another, the eye seems to behold a boy in quick motion through the air. In the first zoetropes the pictures were roughly executed woodcuts, not particularly well drawn. When these were replaced by a series of instantaneous photographs there was a much better illusion of motion, and the toy of Plateau began to unfold its possibilities.

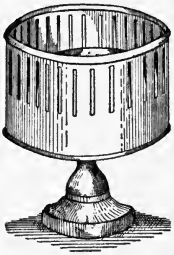
FIG. 85.
Zoetrope.

The Photochronograph.

Much remained to be desired in the portrayals of the zoetrope; it did not enter the door that it opened. To Marey, Edison, and Lumière are chiefly due the machines which gave the camera its mastery of motion—in addition to its preceding conquests of form, colour, and solid relief. Marey, in his photochronograph, has given his attention mainly to problems of science: he has demonstrated how a cat manages so to fall through the air as to alight on its feet; he has analysed the movements of walking, running, and swimming.[1] In comparing the locomotion of man and the lower animals he has come upon more than one striking similarity. The eel in the water and the adder on the ground move by undulations of precisely the same kind. When a tadpole's tail drops off, its hind feet move exactly as do the limbs of a human swimmer. The engineer, as well as the biologist, propounds questions of moment to the Marey machine. By means of its testimony, M. Deslandres has investigated the strains to which bridges are subject under a moving load. In one startling case he

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[1] *Movement.* E. J. Marey. International Scientific Series.

found that when the steps of a horse, harnessed to a carriage, harmonised in rhythm with the natural vibrations of the structure, the deflection of a bridge became thirteen times as great as when the horse and carriage stood still.

Strange stories come to us from Hindostan of a wizardry which plants a seed and obliges the stem to sprout, grow, blossom, and bear fruit, all in a few minutes. Photography displays an equal marvel, but substitutes seconds for minutes. M. Mach, selecting a gourd of rapid growth, took pictures of it twice a day for fifty days, and when these pictures were combined, zoetrope fashion, they vividly recalled the history of the plant. Apart from the phenomena of growth proper, which were interesting enough, the leaves were seen to turn to the light in the most natural manner, while the relative repose of the later stages of maturing was clearly manifest.

The Kinetoscope.

Edison, in devising the kinetograph, which takes his pictures, and the kinetoscope, through which they are viewed, has paved the way for researches quite as fruitful as those of Marey, but thus far his selection of subjects has been in the field of amusement rather than of instruction. The pictures of the kinetograph are taken at intervals of one forty-sixth of a second, the exposure lasting one-sixtieth of a second (Plate XIV). In such figures one gets an idea of the mechanical resources upon which rest the advances of modern photography. The images duly impressed on a narrow strip of celluloid, which resumes its journey 2760 times a minute, are developed by carefully timed machinery. When such a strip is brought into the kinetoscope, and moved and halted at precisely the same intervals as those of its impress, the illusion of movement is irresistibly conveyed. By means of a stereopticon the pictures are thrown upon a screen with vivid effect, especially in recall-

PLATE XIV.

EDISON KINETOGRAPHIC PICTURES.

A dance.

ing the swift motion of water—the dash of breakers against a cliff, the rush and tumult of the rapids and falls of Niagara, the ebullition and subsidence of a Yellowstone geyser. Of course, where the movements depicted are comparatively slow the pictures have their best opportunity to fuse without the provoking breaks and glinting of an ordinary series.[1]

The Pilgrims of the Sky.

An astronomer it was who, as long ago as 1874, came within an ace of inventing the kinetoscope. In that year M. Janssen was able to determine the phases of Venus as she crossed the solar disc by means of a succession of instantaneous photographs. Had he placed these in a zoetrope the transit of the planet would have reappeared the moment that the toy was rotated. Now that the kinetoscope and its sister, the kinetograph, have come to virtual perfection, astronomers adopt both in bringing before popular audiences many splendid phenomena until lately known solely to the telescopic observer. Large assemblies in many great cities of the world are to-day aroused to enthusiasm as the weird splendours of a solar eclipse are thus recalled before their eyes. We are promised next a similar view of the sun in its full swing of rotation, spots and all; this would not be more marvellous than M. Flammarion's pursuing the moon in its movements across the heavens from sunset to sunrise, and bidding it repeat the pilgrimage on canvas.

In humbler walks than those of the sky, the photography of motion has been widely utilised. It catches the movements of the lips and tongue, and repeats them without variation or weariness for the instruction of deaf-mutes. It teaches the arts of swimming, driving, and piano-play-

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[1] Detailed information, fully illustrated, is given in *Living Pictures*, by Henry V. Hopgood. London, *Optician and Photographic Trades Review* Office, 1899.

ing; it tells how the Deccan peasant plies the shuttle for the fabric so like gossamer that it is known as the "woven wind," and how the Australian throws the boomerang so that it returns to his feet. It registers the uneasy sliding of the hull of a man-of-war as it leaves its launching-cradle for the sea. It promises to aid the art of medicine by portrayals of tetanus and epilepsy to be studied and compared at leisure. M. Doyen, a distinguished French surgeon, has committed all the details of a capital operation to kinetographic films, with a teaching effect nearly as satisfactory as if the students stood beside the operating-table.

A New and Faithful Instructor.

In the field of mechanics the reproduction of movement opens quite as wide a door as that of an isolated view, especially now that the process of obtaining kinetographic films has been much simplified. The kinetoscope may easily magnify mechanical motions which are thoroughly mysterious to most of us, albeit that they take place in the commonest machines. Let the action of a type-writer, a sewing-machine, a printing-press, or a trolley motor be purposely retarded, and a series of its photographs would resolve many an every-day puzzle.

The race is not always to the swift; it is with plates of old-fashioned slowness that composite photographs are secured with their singular creations, unknown before the camera gave them birth. An operator reduces his light so that a plate will require twenty seconds for a complete impression. Twenty faces, either directly or from good negatives, and all in the same position, are successively imprinted upon it, each for a single second; the result is to "bring into evidence all the traits in which there is agreement," and to leave "but a ghost of a trace of individual peculiarities," as stated by Mr. Francis Gal-

Composite Photographs.

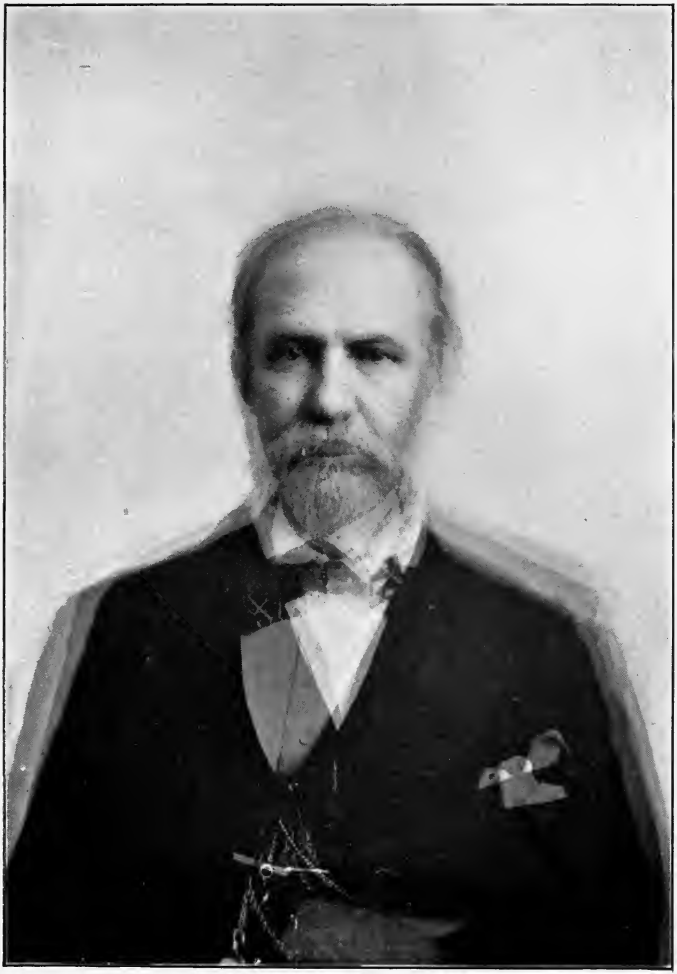

PLATE XV

COMPOSITE PORTRAIT OF EIGHT MEMBERS OF THE NATIONAL ACADEMY OF SCIENCES.

ton, the inventor of the process.[1] Hence a striking addition to the portrait gallery of mankind—in typical faces of school-girls, philosophers, physicians, Saxon soldiers, motormen, Apaches, or men of science (Plate XV).[2]

A critic may ask, Are these composites really typical? Verification is easy. Select a class to be photographed—Indians, firemen, or any other you please. Choose at random twenty of their faces and make from them a composite. Then take haphazard another twenty faces from the same class and from them obtain a second composite. The first and second pictures will resemble each other so closely as to leave no doubt of the essential truth and scientific worth of the process. Clearly the day cannot be far off when physiognomy will have a basis in unimpeachable fact—when the conventional caricatures, to-day sadly overworked as national types, will disappear for good and all. When we see the face of a stranger and classify it as that of a Frenchman or a Swede, we do so from residual remembrances which in their first estate may have been but few and not fairly representative, while subject to the distortion and wear that mar all the mintage of the memory, however deep and clear its original stamp. Just as truth has been substituted for tradition in the case of animal movement, so we shall here replace vague impressions of foreigners and of special classes at home by exact and easily compared pictures. For truth very considerably beautified we must, however, be prepared. Dr. H. P. Bowditch, in the illustrations which accompany his article, "Are Composite Photographs Typical Pictures?" in

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[1] *Nature*, May 23, 1878. The subject is further developed in his *Inquiries into Human Faculty*, published in 1883.

[2] Plate XV is from a composite photograph by Mr. Thomas W. Smillie, chief photographer to the United States National Museum, Washington: it represents eight members of the National Academy of Sciences—Spencer F. Baird, Henry L. Abbot, Charles A. Young, A. S. Packard, H. B. Hill, J. M. Crafts, George J. Brush, and William Ferrel.

McClure's Magazine for September, 1894, has shown how much handsomer are the composites derived from Wend soldiers, a dinner club of Boston physicians, and from horse-car drivers, than the individual faces united to create them. This effect is explained by Mr. Galton, who points out that the features of a composite are always regular, since the irregularities, due to individual peculiarities, vanish from the final picture.

The Quest for Expression.

Mr. Galton, in his original description of composite photography, threw out a hint well worth recalling. He said that the camera might easily secure a portrait which would rival the work of the brush. It is the characteristic expression of a face which commonly defies the photographer, and which gives the thoughtfully painted canvas all its value. Now, if a photograph be taken at twenty different times, say a day apart, the setness of an ordinary pose will vanish, and in the various play of natural expression the man himself will stand forth, somewhat as if he gave a good painter a score of sittings. In brief, the faculty of such a painter rests very largely in his brain as the analogue of the composite camera in giving saliency to what in a face is really telling, in dropping out of view the self-conscious stare which a sitter may have at the first séance, and which is too evident in many single-impression photographs. Much was done for portraiture when the time of photography was lowered to virtual instantaneity, so as to catch the features at their best, and before fatigue had lined them; something more may be accomplished by those willing to take the trouble to add composite to simple portraiture. A great deal may be said about the lofty applications of the camera; just as much may be told regarding the exalted work of fire. But as common every-day cooking, to so great a critic as Lord Kelvin, far outranks every other task of flame, so the production of ordinary likenesses of the plain people continues to be the principal mission of the pencil of light. Inasmuch as Mr. Galton's suggestion may better the practice of photographic portraiture, let it, therefore, be heard with respect and receive the careful tests it deserves.

Sometimes a composite, due to combining the portraits of a father and mother, yields a picture bearing a striking resemblance to their children. In a lower branch of the tree of life, Mr. Galton proposes experiments with a view to being able to predict the effect of crossing particular strains of horses and cattle.

Photographic Reproduction: Its Beginnings with Niépce.

When an impression,—a portrait, a landscape, or aught else,—has been secured on a photographic plate, it is often desirable to reproduce it in some inexpensive form suited to the printing-press. In its early days photographic printing was restricted to the methods still in vogue for common portraiture. A negative, and every positive derived from it, had to take its deliberate way through a succession of fixing, toning, and cleansing baths. Was there a feasible mode by which light could yield a picture in relief for use in the common printing-press? Fortunately, yes. In this direction Niépce took a step second in importance only to his original exposure of a film to the action of light. With a view to reproduction he coated a copper plate with asphalt, and impressed it with a picture in his camera. The places not exposed to light remained soluble, and on being washed away left bare parts of the copper surface, which he then etched for use in a printing-press. Heliographs, as he styled the resulting pictures, were found among his papers after his death, and prove how completely he had grasped not only the production but the reproduction of a luminous image.[1]

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[1] Daguerreotypes, despite the extreme delicacy of their relief, may easily and without the slightest injury be copied in a suitable plating bath. A feeble current—which occupies two days for its task—is best.

His etching process is, as we shall presently note, at the foundation of many photo-printing methods now highly developed and widely popular, of which only a few can here be mentioned. There was an early divergence from Niépce's choice of asphalt in favour of a substance possessing the same susceptibility in a much higher degree. This was the compound of gelatin and bichromate of potassium, discovered by Ponton in 1839. A film of this substance may be much thicker than a film of asphalt, and, what is of greater importance, it can be much more quickly impressed with an image; when the gelatin is dissolved away from the portions not acted on by light, the relief which remains can be employed as a mould from which to make a cast in metal for the ordinary printing-press. In a second method, now little used, the unhardened gelatin is not washed out with a solvent, but is carefully swollen with water; from the projections thus formed a metal relief is taken for the printer's use. A process at once simple and excellent in its results is to apply printers' ink directly to a gelatin plate when it leaves the camera; the ink is absorbed solely in those lines and dots of the gelatin which have been protected from light. For quick newspaper work there is recourse to zinc, and a reversion to the original plan of Niépce. A photograph is transferred to the metal in printers' ink, and this ink, as it resists the acid of an etching bath, leaves the uncorroded metal beneath it as a plate in relief for the press.

For the incomparably more delicate work of photogravure, art is indebted to Fox-Talbot as the chief pioneer. He coated a metal plate with the compound of gelatin and bichromate of potassium, and, after he had impressed it with an image in the usual way, immersed the plate in an etching fluid. Where light exerted no effect the film allowed the liquid to pass readily; where the light had acted to the full the gelatin was impervious. Between these extremes of light and darkness there were all degrees of resistance to the passage of the biting fluid. The principal mode of modern photogravure is Klic's modification of Fox-Talbot's process; the film of chromated gelatin, hardened by the action of light, is transferred to a metal plate after exposure. The gelatin which remains unaffected by light, and therefore insoluble, can thus be readily washed away with warm water, leaving on the metal plate a resist of graduated thickness. By the utmost nicety of manipulation such a plate is capable of reproducing in ink almost all the beauty of an original masterpiece.

The Carbon Process.

Another remarkable branch of reproductive art is due to Poitevin, who, in 1855, was the first to incorporate a pigment with a film of sensitised gelatin. He thus founded what has since been splendidly developed as the carbon process. In present practice a sheet of paper coated with a mixture of gelatin, sugar and colouring matter, is sensitised by being floated in a solution of potassium bichromate. At the points where light falls in the camera, the tissue is hardened; at points of darkness it remains soluble. When the soluble portions are washed away a picture is left behind in an unchangeable pigment. The "gum bichromate" process, which of late years has produced so many beautiful results, is a modification of the method introduced by Poitevin.

Half-tone.

Photographic printing branches out into many and increasing alliances with etching, engraving, and lithography. The simplest of them render only lines such as those of an architect's plan, or of a manuscript in facsimile. How can the half-tone, the graduated shadow so essential to a picture, be expressed? The usual method is to interpose between the gelatin and the original sketch or picture to be copied, a network of fine lines ruled near together on a glass plate, with the effect that, if inspection be not too close, a faithful transcript in dots seems conveyed to the plate. What this network or screen does is to break up the impressed picture into minute points which catch the ink from the roller of the printing-press; the interstices between point and point being untouched by the ink, the picture is presented in what may be considered as stipples of refined character. In common work the rulings of the screen are about eighty to the inch; in the illustration of the best books and magazines the rulings are twice as many, or even more. The portraits in this volume are executed in half-tone. When magnified, as in Fig. 86, we can understand how much the suggestions of the mind piece out and complete the crude outlines of a "process" picture. "The eye sees what it brings with it the power of seeing."[1]

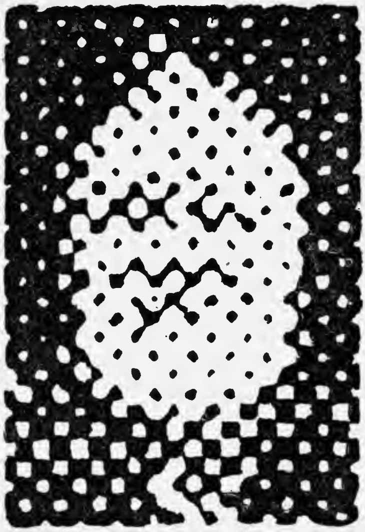

FIG. 86.

Much enlarged from a half-tone portrait of Lord Kelvin. From the *Journal of the Amateur Photographic Society of Madras.*

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[1] The United States National Museum, at Washington, contains an admirable collection of photographs illustrating in detail every application of the camera, and the chief reproductive processes based on photography.

CHAPTER XXIII

THE PHOTOGRAPHY OF THE SKIES

The Beginnings.

DR. JOHN W. DRAPER, who, as we have already noted, was the first to portray the human face in the camera, was also the first to photograph a heavenly body. In March, 1840, he succeeded in taking pictures of the moon, which were fairly good, considering the imperfection of his instruments. Five years later Professor G. P. Bond, at Harvard Observatory, obtained clear portraits of the moon with a 15-inch refractor, and in so doing launched his observatory on a career of astronomical photography which to-day gives it the lead in all the world. From 1865 to 1875 Mr. Lewis M. Rutherfurd of New York took photographs of the moon which for twenty years were unrivalled. At present the moon is the best photographed of all celestial objects, and yet Professor Barnard says that the best pictures thus obtained come short of what can be seen with a good telescope of very moderate size. Thus far minute details of the surface are beyond the reach of photography, but its accurate delineation of the less difficult features is of the highest value.

"The photography of the surface features of the planets," adds this observer, "is in an almost hopeless condition at present; yet much may be expected when an increased sensitiveness of plates has been secured." No plate as yet produced is fully responsive throughout the whole range of the telescopic eye. Clearly enough, the draughtsman has not been ousted from every corner of the observatory as yet, although in most of its tasks his services have long ceased to be required; in one of them the embarrassment of the camera is not a lack but an excess of light. Professor Janssen of the observatory at Meudon, near Paris, long ago succeeded in making the best photographs of portions of the sun's surface; he has always used the wet-plate process, which, from its slowness, gives the best results with the intense solar beam.

Old and New Methods of Picturing Eclipses.

Just at the turning-point between old and new methods of recording the phenomena of the sky, there was a contrast between them which was decisive. On July 29, 1878, a total solar eclipse was so widely observable throughout the United States that forty to fifty drawings were made of the corona, duly published by the United States Naval Observatory, Washington, two years afterward. Says Professor Barnard: "On examination scarcely any two of them would be supposed to represent the same object, and none of them closely resembled the photographs taken at the same time. The method of registering the corona by free-hand drawing under the conditions attending a total eclipse received its death-blow at that time, for it showed the utter inability of the average astronomer to sketch or draw under such circumstances what he really saw." Compare the pencil with the camera in one of its recent achievements. On January 22, 1898, Mrs. Maunder, with a lens only one and a half inches in diameter, secured impressions of swiftly moving coronal streamers about five million miles in length. It is evident enough that the pencil cannot compete with the camera in depicting the extremely brief phenomena of an eclipse, and it is also plain that an instrument of moderate size and cost is quite sufficient for good work.

Often the images of the telescope are not fleeting, and remain visible quite long enough for a draughtsman to catch their outlines; but other circumstances than those of time forbid the use of his pencil. Professor E. E. Barnard has taken observations at the Lick Observatory when the thermometer has stood at −32° C. At such a temperature a camera may be used, while to employ a pencil is out of the question.

An Untiring Eye.

In many tasks, where extremes of cold or heat do not trouble him, the astronomer is glad to avail himself of the quickness of the sensitive plate, which so far transcends the celerity of the eye. If in its rapidity of response a quick plate is superior to the retina, it has the further advantage of being exempt from fatigue. Light much too feeble to excite vision can impress an image on a sensitive plate if it be given time enough. During four hours ending at two o'clock in the morning, M. Zenger has taken photographs of Lake Geneva and Mont Blanc when nothing was perceptible to the eye. Turned to the heavens, this power to grasp the invisible brings to view a breadth of the universe unseen by the acutest observer using the most powerful telescope. Let the lenses of such an instrument be directed to a definite point in the sky by accurate machinery, and they will maintain their gaze with accumulating effect upon a sensitive plate through all the hours of a long night, and, if need be, will renew their task the next night, and the next.

In this work the utmost mechanical precision is imperative. Professor E. E. Barnard says that if the motion of a guiding clock varies as much as $\frac{1}{1000}$ of an inch during an exposure of from three to eight hours, the images are spoiled and worthless. It was only after repeated failure that mechanicians were able to make a clock sufficiently accurate to keep a star image at one fixed point on a plate. Steadily caught at one unchanging place, a ray, however feeble, goes on impressing the pellicle of a plate, minute after minute, hour after hour, night after night, until at last, by sheer persistence, the light from a star or a nebula too faint to be detected in a telescope imprints its image. Some images have been obtained as the result of twenty-five hours' exposure during ten successive nights, so as to get impressions from as near the zenith as possible, where atmospheric disturbances work least harm because atmospheric paths are there at their shortest. Myriads of heavenly bodies have thus been added to the astronomer's ken, which, without the dry plate, would probably have remained unfound forever.[1]

When Dr. Maddox was busy stirring together his bromides and gelatin he did not know that from his bowl the universe was to receive a new diameter; but so it has proved. The invention of the telescope marks one great epoch in the astronomer's advance; another era, as memorable, dawned for him when he added to the telescope a camera armed with a gelatin film. He gained at once the power of penetrating depths of space which otherwise would never have sped the explorer a revealing ray. As the camera outranges the eye, in that very act it surpasses every task of depiction which the eye may dictate to the hand.

So efficient is the scouring of the heavens by the telescopic camera that to its plates is now resigned the search for those little worlds, or world-fragments, known as asteroids. The hunt is simplicity itself. A plate is exposed in a camera, and directed by clockwork to a particular point in the sky for two or three hours. Because the stars are

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[1] See a superbly illustrated article by Professor E. E. Barnard, *Photographic Times*, August, 1895.

Asteroids Discover Themselves.

virtually motionless in a time so short, they register themselves as tiny round dots. The asteroids, on the other hand, have an appreciable motion across the field of view, somewhat as the moon has, and so they betray themselves as minute but measurable streaks. On August 13, 1898, a streak of this kind disclosed to Herr Witt at the Observatory of Urania, at Berlin, that most interesting and important of all asteroids, Eros, about ten miles in diameter, which approaches the earth more closely than any heavenly body but the moon. It is expected that observations of Eros will enable astronomers to revise with new precision their computations of the distance of the sun and the planets. A faint streak similar to that observed by Herr Witt once told Professor Barnard that a comet had passed in front of his telescope—a comet so small and flimsy that only a photographic plate could see it. Early in 1899 Professor William Pickering thus discovered a new satellite of Saturn, making its known retinue nine in number. This new moon made its appearance on four plates exposed with the Bruce telescope at Arequipa, in Peru. Its light is so faint that no telescope in existence is powerful enough directly to disclose the tiny orb (Fig. 87).

FIG. 87.

Satellites of Saturn. Phœbe, the ninth, discovered by Professor William Pickering.

Where direct vision is easy, the camera enables the photographer to save time in an astonishing way. Professor Common's photograph of the moon, taken in forty minutes, rewarded him with as full detail as had four years' work with the telescope and pencil. Often an image seen only in part in the telescope is completed with wonderful beauty in the camera. The streaming tail of a comet is frequently doubled or trebled in length as it imprints itself upon the gelatin plate. Brooks's comet of 1893, in one of its photographs taken with the Willard lens at Lick Observatory, showed its tail as if beating against a resisting medium, and sharply bent at right angles near the end, as if at that point it encountered a stronger current of resistance. Many nebulæ, those of the Pleiades especially, appear in much greater extent and detail in a photograph than to an observer at the eye-piece of a telescope. Their rays are particularly rich in the vibrations which affect the sensitive plate, but to which the eye is irresponsive.[1]

Forty Minutes instead of Four Years.

More than once a word has been said about the unsuspected worth of the incidental; celestial photography supplies a capital illustration. In 1882, at the Cape of Good Hope, when the great comet of that year appeared, it occurred to Dr. Gill, the director of the observatory, that it might be possible to photograph it. To the telescope, pointed at the comet, a small camera was accordingly attached. After a short exposure the plate was developed and the image of the comet came into view. So far as is known, this was the first comet ever photographed. The plate, moreover, showed not only the comet which had been sought, but also stars which were unsought, and that were quite invisible in the telescope (Plate XVI). From their images, thus unwittingly secured, came the project of a new map of the heavens, which should reveal its orbs to

Accident and Essence.

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[1] Address of Professor E. E. Barnard as vice-president of Section A,—mathematics and astronomy,—American Association for the Advancement of Science, 1898.

Plate XVI.

PHOTOGRAPH OF COMET BY DR. DAVID GILL, 1882.

With incidental portraiture of stars invisible in the telescope.

the limit of a plate's impressibility. With the Observatory of Paris as their centre, astronomers throughout the world are now engaged upon a chart of the sky which will contain at least twenty million stars. In future generations a comparison of the pictures now in hand with pictures of later production will have profound interest. Stellar changes of place and nebular alterations of form will indicate the laws of the birth, the life, the death of worlds.

At the close of the year 1899 there were stored at Harvard Observatory 56,000 plates depicting the heavens during every available night beginning with 1886. Doublet lenses, of much wider field than the single lenses usually employed, have been chosen by Professor E. C. Pickering, the director, for this work. Thanks to their use, certain of the plates have been found to bear images of Eros, impressed at intervals for years before the discovery of the asteroid at Berlin. These impressions indicate a considerable portion of the orbit of the object. Records of equal value doubtless remain to be detected in this remarkable portrait-gallery of the skies.

What Colours Tell.

In the moments which follow striking a match in the dark, we see in succession the hues proper to burning phosphorus, to sulphur, and to the carbon of the match-stick. In a display of fireworks the combustibles are chosen for a display of colour much more variegated and brilliant. We recognise at once the yellow flame of sodium, the crimson blaze of strontium, the purple glitter of zinc aflame. These and all other elements when they reach glowing heat give out light of characteristic hues; to examine them minutely a spectroscope is employed. In its essence this instrument is a glass prism which sorts out with consummate nicety the distinctions of colour and line borne in the light of the sun, or a star, or a meteor, or of the fuel ablaze in a laboratory furnace. Every ray as it passes through a prism is deflected in a degree peculiar to its colour: violet light, at one end of the rainbow scale, is deflected most; red light, at the other end, is deflected least. It is because solar and stellar beams display the characteristic spectra of sodium, iron, hydrogen, and many other terrestrial elements, highly individualised as each of them is, that we know that the sun and the stars are built of much the same stuff as the earth.

In passing from the colours of the solar spectrum to its many minute interruptions, "the new astronomy" began. As photographed by Professor Rowland upon sheet after sheet for a total length of forty feet, the spectrum of the sun is crossed by thousands of dark lines. The interpretation of the most conspicuous of these lines by Bunsen and Kirchhoff, in 1859, marks an epoch in the study of the heavens. Let us approach their explanation by a simple experiment. If we sing a certain note upon the wires of an open piano, just that string will respond which, if it were struck, would utter that note. Precisely so when we pass from vibrations of sound to those of light; a vapour when cool absorbs by sympathy those waves of light which, if it were highly heated, it would send forth. Hence the dark lines in the solar spectrum tell us what particular gases, at comparatively low temperatures, are stretched as an absorbing curtain between the inner blazing core and outer space. To choose a convincing example: when the spectrum of the sun and that of iron are compared side by side in the same instrument, bright lines of the iron coincide with dark lines of the solar spectrum (Plate XVII).

The tints and lines of a spectrum, whether from the sun or a star, disclose not only the character but the consistence of the elements which send them to the eye or to the photographic plate. Hydrogen, for example, when it burns at ordinary pressures, as it may in the simplest laboratory experiment, emits a spectrum of bright lines crossed by sharp thin lines of darkness. These bright lines, when the gas has high pressure, broaden out and become almost continuous, so as to resemble those emitted by a glowing solid. Hence an astronomer is told by one particular spectrum that it comes from a star having a highly condensed gaseous core, while another spectrum betokens a true nebula—a vast body of gas aglow in extreme attenuation. A spectroscope, therefore, reveals not only what a heavenly body is made of, but also the physical condition in which its substance exists, whether as a solid, a liquid, or a gas.

Lines Out of Place Disclose Much.

The lines in a stellar spectrum are liable not only to be broadened out, but to be shifted from their normal place, and this shifting has profound significance, according to a principle first announced by Christian Doppler in 1841. If a star is at rest, relatively to the earth, the tints and lines of the elements aglow on its surface will have positions in its spectrum as changeless as those due to the iron, or the sulphur, aflame on the chemist's tray. But if the star is moving toward the earth, or away from it, the spectral lines will appear a little to the right or left of their normal position, and in so doing disclose the rate of approach or recession. To understand this we have only to enter the field of acoustics. Suppose that a listener takes up his post midway between two railroad stations somewhat distant from each other. As a locomotive approaches him let us imagine that its whistle is blown continuously. To the engineer on the foot-board the whistle has a certain note; to the listener who is standing still the whistle has a somewhat shriller note, because the motion of the engine toward him has the effect of shortening the sound-waves, and shrillness increases with the shortness of such waves—with the greater number per second which he hears. If all the engines of the line have whistles exactly alike, a listener with his eyes shut can easily tell whether it is a freight-train that is advancing, or an ordinary express, or a "limited" running at fifty miles an hour; the quicker the train, the shriller the sound of its approaching whistle (Fig. 88). Sir William Huggins, the pioneer in applying this principle to reading stellar motions, adopts a parallel illustration: "To a swimmer striking out from the shore each wave is shorter, and the number he goes through in a given time is greater than would be the case if he stood still in the water."

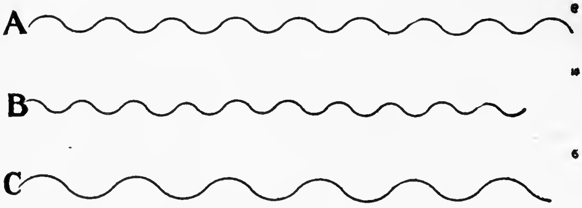


Fig. 88.

A, waves between two points at rest relatively to each other.
B, waves between two points at a shortening distance apart.
C, waves between two points at a lengthening distance apart.

Let us now return to the sister phenomena of light. At one end of the visible spectrum the violet rays have about half the length of the red rays at the other end of the scale; accordingly about twice as many violet as red rays enter the eye in a second. Let us imagine a star like Betelgeux, which, at rest, would emit red rays solely. If such a star were to rush toward the earth with the speed of light, 186,400 miles a second, its rays would be so much shortened as to be halved in length, and the star would appear violet—its characteristic hues and lines showing themselves at one extreme of the visible scale instead of at the other. Of course, no star moves toward the earth with more than a small fraction of the speed of light, and yet so refined is the measuring of the displacement of spectral lines that a motion toward the earth of somewhat less than one mile in a second can be readily determined. In the case of Betelgeux its movement toward the earth is known to be 17.6 miles a second, about $\frac{1}{11000}$ part of the velocity of light, the displacement of its red lines toward the violet end of the scale being about $\frac{1}{11000}$ part of the whole length of the spectrum. If, in a contrary case, a star is receding from the earth, its spectroscopic lines will be shifted toward the red end of the scale, just as a locomotive whistle falls to a lower pitch as the engine moves away from a listener standing still. By this method Gamma Leonis is known to be travelling away from us at the rate of 25.1 miles a second. In this unique power of detecting motion in the line of sight, the spectroscope when furnished with a sensitive film enormously enhances the revealing power of the telescope.

Solar and Stellar Spectra.

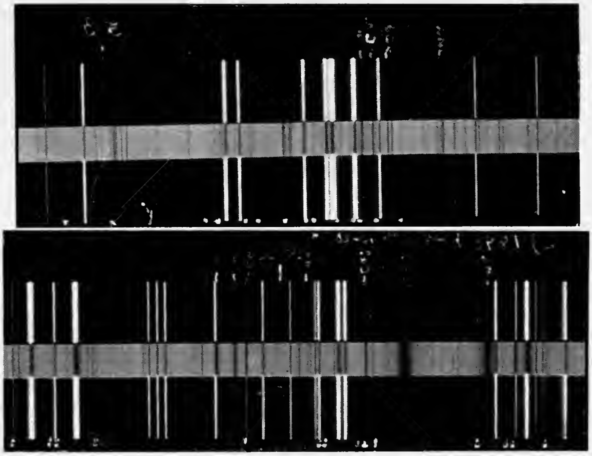
The sun was, of course, the first heavenly body to have its spectrum caught on a sensitive plate. In 1863 Dr. (now Sir) William Huggins attempted to photograph the spectrum of a star. He obtained a stain on his plates, due to the spectra of Sirius and Capella, in which, however, no spectral lines were discernible. In 1872 Dr. Henry Draper of New York obtained a photograph of the spectrum of Vega, in which four lines were shown; this was the first successful picture in the series which Dr. Draper gave to the world during the following ten years. Since his death, in 1882, Mrs. Draper has established the Draper Memorial at Harvard Observatory, for the continuance of his labours on an extended scale. The photographs by this Memorial owe much to the Vogel method, by which the plates are sensitised for green, red, and yellow rays. Were this sensibility to colour still further increased, the photographs of stellar spectra would tell a yet fuller story than they do to-day. Owing to irregular atmospheric currents, the image of a star dancing around the narrow slit of a spectroscope may elude even a practised observer. Photography, with its summation of recurrent impressions, gives a perfectly uniform image of the composite type which Mr. Galton introduced in human portraiture. That image, for all its minuteness, may bear a most informing superscription:

In the northwestern sky one may observe the constellation of the Charioteer—to most advantage in April or May.

Twin Stars.

At Harvard Observatory, in 1889, it was remarked that a spectrum from a star in that constellation, Beta Aurigæ, varied from night to night in a singular manner. The cause was found to be that the light comes, not from a single star, but from a pair of stars, periodically eclipsing each other, and having a period of revolution of slightly less than four days. In determining the rate of motion of these stars as 150 miles a second, their distance from each other as 8,000,000 miles, and their combined mass as two and three-tenth times that of the sun, Professor Pickering regards the prism as multiplying the magnifying power of the telescope about five thousand times. To a telescope such a double star appears as but a single point of light; in a spectroscope each component star reveals its own spectrum. When the star is approaching the earth its spectral lines are shifted to the violet end of the scale; when the star is receding from the earth, its lines are displaced to the red end of the scale. In the case of Beta Aurigæ the change in the spectrum is so rapid that it is sometimes perceptible in quickly successive photographs, and becomes very marked in the course of an evening:

Plate XVII illustrates this phenomenon. In Fig. 1 the theoretical curve during December, 1889, is represented by the sinuous line, abscissas indicating times, and ordinates the corresponding separations of the components of the *K* line. The black circles



SOLAR SPECTRUM COMPARED WITH THAT OF IRON.
(See p. 332.)

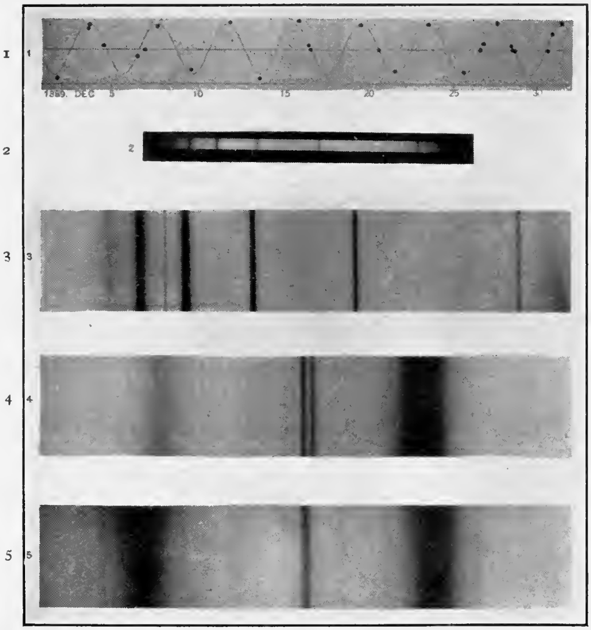


PLATE XVII.

SPECTRA OF BETA AURIGÆ.
(See p. 337.)

represent the twenty-seven photographs taken during this month, their ordinates representing the result of a rough measure of the separation of the lines. In no case does the observed position differ from that given by theory by more than the accidental errors of measurement. Fig. 2 is a contact print from the original negative taken December 31, 1889, at 11 *h.* 5 *m.*, Greenwich mean time. Fig. 3 is an enlargement with cylindrical lens of this same negative. Fig. 4 represents a still greater enlargement of the same negative, and shows the *K* line distinctly double; by shading one part of the photograph the strong line *a* to the left of *K* is also shown in the enlargement to be double. . . . Fig. 5 is a similar enlargement of a negative taken December 30, 1889, at 17 *h.* 6 *m.*, Greenwich mean time, eighteen hours previous to Fig. 4. The lines here are single.[1]

This subtile means of detection is set upon the track not only of double stars, but on that of such a star as Algol, which is attended by a planet so large as to eclipse it almost wholly in a period somewhat shorter than three days.

These binary systems, so different from any previously known, would in all likelihood have been hidden for ages to come but for photography, because until that discovery was made there was no apparent reason for every-day examination of the spectrum of a star. Indeed, until then, when the lines were once carefully measured, they were put aside by the observer as finished and definite records of the star's spectrum. These first results indicate that the components of Beta Aurigæ are separated by an angular interval of only $\frac{1}{900,000}$ part of a degree, a quantity so small that twenty years ago no one would ever dream of being able to measure it.[2]

New demands give the eye new refinements: the duplicity of the spectral lines of Beta Aurigæ was discovered by Miss A. C. Maury. Mrs. W. P. Fleming of Harvard Observatory has become so expert in detecting variable stars by their spectra that she recognises them instantly

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[1] Henry Draper Memorial, Fourth Annual Report, Cambridge, Massachusetts, 1890.

[2] Address by Professor H. C. Russell, government astronomer, Sydney, to Section A,—astronomy, mathematics, and physics,—Australian Association for the Advancement of Science, 1893.

among hundreds of other spectra on the same plate. And mark the value of these photographic spectra for subsequent investigation. Mrs. Fleming says: "While an astronomer with a telescope, be it ever so powerful, is at the mercy of the weather, the discussion of photographs goes on uninterruptedly, and is much more trustworthy than visual work, since, where a question of error arises, any one interested in the research can revise the original observation by another and independent examination of the photograph."[1] During the eight years beginning with 1892, four stars of more than the ninth magnitude were added to the charts of astronomy; in every case the discoverer was Mrs. Fleming as she detected the spectrum of a new star in celestial photographs.

The Rings of Saturn are Meteoric.

Professor J. Clerk-Maxwell was of opinion that the rings of Saturn are simply aggregates of meteorites which preserve their outline by swift rotation. His belief has been verified by Professor James E. Keeler at the Allegheny Observatory, his spectroscope proving that the inner edge of each ring moves more swiftly than the outer edge. If the ring were a solid body the reverse would be the fact, and the lines in its spectrum would be very nearly continuations of the lines in the spectrum of the central ball. So refined is this field of inquiry that the astronomer's reliance is upon a micrometer exquisite enough to measure a space of $\frac{1}{10000}$ of an inch on a photograph.[2]

The latest chapter in the story of the solar spectrum has been added by Professor George E. Hale, director of the Yerkes Observatory. An ordinary spectroscope has a slit through which a narrow ray of light passes into a prism for dispersion. To this slit Professor Hale adds another

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[1] *Astronomy and Astrophysics*, October, 1893, p. 687.

[2] "Some Notes on the Application of Photography to the Study of Celestial Spectra," by James E. Keeler, *Photographic Times*, May, 1898.

The Spectro-heliograph.

which permits only light of a single colour to reach his photographic plate. Because this light is of but one hue, pictures can be obtained of objects not to be photographed in any other way. Moving the apparatus at will, he secures photographs of the prominences round the edge of the sun, as well as of the whole surface of its disc. A visual examination of the prominences would require two hours, but pictures of them may be taken in two minutes. Many faculæ, undiscernible by any other means, have been brought to view by Professor Hale's instrument, which he calls the spectro-heliograph. The device was suggested by Janssen as long ago as 1869; it was independently invented by Professor Hale in 1889.

Singular Discoveries.

The extension of disclosures by the camera in regions blank to the eye seems without bound. Beyond the violet ray of the solar spectrum extend vibrations which, though invisible, have been caught on photographic plates ever since the experiments of Scheele in 1777. Victorium, an element recently discovered by Sir William Crookes, has a spectrum high up in the ultra-violet region, which, therefore, can be studied only photographically. More than one element has made its first appearance to the chemist as he has observed the spectrum of the sun. Helium thus introduced itself long before its discovery in the atmosphere of the earth. Coronium, which appears in the solar corona, has been diligently searched for, especially in the tufa of volcanoes, but thus far without assured results.

Toward the end of the spectrum, beyond the red, are invisible radiations which evaded capture until 1887, when Captain Abney secured an image from them on a bromide-of-silver plate. He maintains that in the use of plates sensitive to such ultra-visible rays, astronomers have a new means of exploring the heavens, and are free to enter upon a fresh chain of discoveries. To the stars already known it is in their power to add two classes as yet unseen—stars newly born or newly dead, whose temperatures in consequence are below the range of visible incandescence.

Nebular Evolution.

When light succeeded the pencil as a limner of nebulæ there was the keen interest that attaches to the calling of a new witness in a case before the highest court—a witness so much more observant and alert than any other, so absolutely devoid of bias or prejudice, that his evidence decides the verdict. For a century and more the nebular hypothesis of the universe, propounded by Kant and Laplace, had been vigorously debated by astronomers and physicists. The great telescopes of the two Herschels had enabled observers to descry nebulæ having the shapes which vast cloudy masses would assume in the successive phases of condensation imagined in the theory. Some were spherical in form, others were disc-like, yet others were ring-shaped, and the most significant outline of all, that of a spiral, was also discerned. But when Lord Rosse's great reflector was turned upon certain of these masses they were resolved into stars, and a good many critics said that, given telescopes sufficiently powerful, all nebulæ would in the same manner prove to be nothing else than stars. A few years afterward the spectroscope was employed by the astronomer, and soon it discriminated between seeming nebulæ, which are really star clusters, and true nebulæ, which are only the raw material from which stars are condensed. In the evening of August 29, 1864, the spectroscope, attached to a telescope, was for the first time directed to a nebula—the planetary nebula in Draco, by Dr. (now Sir) William Huggins. This is what he saw:

> The riddle of the nebulæ was solved. The answer, which had come to us in the light itself, read, Not an aggregation of stars,

PLATE XVIII.

THE NEBULA IN ORION.

From the drawing by Professor G. P. Bond, 1859–63.

Plate XIX.

THE NEBULA IN ORION.

Photographed at Lick Observatory, November 16, 1898.

but a luminous gas. Stars after the order of our own sun, and of the brighter stars, would give a different spectrum; the light of this nebula had clearly been emitted by a luminous gas. With an excess of caution, at the moment I did not venture to go further than to point out that we had here to do with bodies of an order quite different from that of the stars. Further observations soon convinced me that, though the short span of human life is far too minute relatively to cosmical events for us to expect to see in succession any distinct steps in so august a process, the probability is indeed overwhelming in favour of an evolution in the past, and still going on, of the heavenly hosts. A time surely existed when the matter now condensed into the sun and planets filled the whole space occupied by the solar system, in the condition of gas, which then appeared as a glowing nebula, after the order, it may be, of some now existing in the heavens. There remained no room for doubt that the nebulæ, which our telescopes reveal to us, are the early stages of long processions of cosmical events, which correspond broadly to those required by the nebular hypothesis in one or other of its forms.[1]

The first photograph of a nebula, that of Orion, was taken by Dr. Henry Draper on September 30, 1880. In the following March he took another in a little more than two hours, which, for nearly every purpose of study, was incomparably better than the drawing that had occupied Professor Bond for every available hour during four years ending with 1863. Better still is the photograph secured in but forty minutes with the Crossley Reflector at Lick Observatory, November 16, 1898 (Plates XVIII and XIX). Dr. Isaac Roberts of Crowborough, in England, is a successful photographer of nebulæ, and his pictures are instructive in the extreme because he compares them with pictures of stellar systems; between the two he finds a connection strongly suggestive of derivation.

To begin with, he shows a number of photographs of star regions in which the stars can be seen grouped into semi-circles, segments, portions of ellipses, and lines of various degrees of curvature. Some of these groups are composed of stars of nearly equal magnitude; some of faint stars, also of nearly equal

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[1] *Nineteenth Century*, June, 1897.

magnitude; while the distances between the stars are remarkably regular. Passing from these characteristics of stellar arrangement to photographs of spiral nebulæ, Dr. Roberts points out that the nebulous matter in the spirals is broken up into starlike loci, which in the regularity of their distribution resemble the curves and combinations of stars exhibited by photographs upon which no trace of nebulosity is visible. It seems, therefore, that the curvilinear grouping of stars of nearly equal magnitude gives evidence that the stars have been evolved from attenuated matter in space by the action of vortical motions and by gravitation. Exactly how the vortical motions were caused, or what has brought about the distributions of nebulosity in the spiral nebulæ, cannot be answered; but the marvellous pictures of Dr. Roberts establish the reality of the grouping, and furnish students of celestial mechanics with rich food for contemplation.[1]

As Professor Bond drew the nebula of Andromeda with his eye at the best telescope he could command, he depicted dark lanes which come out in a photograph as divisions between zones of nebulous matter. What appeared to be accidental and enigmatical vacuities are shown to be the consequences of cosmogonical action. The hypothesis of the formation of worlds from nebulæ is thus confirmed, if not demonstrated, by the discovery of this new link to connect celestial species. The spiral nebula in Canes Venatici exhibits in a most unmistakable manner a "fluid haze of light," eddying into worlds, and enables us to see cosmic processes at work.[2]

This nebula may be instructively compared with the ring nebula in Lyra (Plate XX).

Beyond and above any single photograph of a nebula, the camera proves that nebulæ are much vaster than they appear in the most powerful telescope, and this fact strongly supports the hypothesis of Kant and Laplace as to the origin of the universe. In two particulars, however, that hypothesis has been modified by the advance of physical and mathematical research. It was originally framed

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[1] *Nature*, March 3, 1898.

A second volume of Dr. Roberts's *Photographs of Stars, Star Clusters, and Nebulæ* was published in December, 1899, by Witherby & Co., 326 High Holborn, London. It contains seventy-two photographs printed in collotype from the original negatives, with descriptive and explanatory letterpress.

[2] *Nature*, March 10, 1898.

GREAT SPIRAL NEBULA IN CANES VENATICI.
(Enlarged 3 diameters.)
Taken in 3 hours with 8-inch refractor. Goodsell Observatory, Northfield, Minnesota.

PLATE XX.

RING NEBULA IN LYRA.
(Enlarged 5 diameters.)
Taken in 2 hours with 8-inch refractor. Goodsell Observatory, Northfield, Minnesota.

long before the relations of heat to its sister forces were understood. It is not now deemed necessary to suppose that the primal temperature of the universe was high; the collision of its particles, as attracted together by gravitation, is a quite sufficient explanation of the heat which a star may exhibit when first condensed. Nor is it necessary to suppose that the original condition of cosmical matter was that of a gas; it may have been that of fine dust, or even an aggregation of meteorites, such as those which still rotate around the central ball of Saturn. Professor George H. Darwin says that a meteoric swarm, seen from the distance of the stars, would behave like a mass composed of continuous gas.

The triumphs of light in the astronomical camera but re-affirm the solidarity of nature, testifying once more that any new thread caught from her skein leads the explorer not only through labyrinths which puzzled him of old, but to new heavens otherwise hidden for all time. Nothing within human knowledge is more marvellous than the agency, apparently so simple, concerned in all this. A ray of light, infinitesimal in energy, persists on its way, for years it may be, through the whole radius of the universe, untired, untolled; its undulations, intricate beyond full portrayal, arrive with an unconfused story of the physical consistence and chemical nature of their source, of the atmosphere that waylaid them, of the direction in which, and at the rate at which, their parent orb was spinning or flying when the ray set out for the earth.

To men of old who knew only what had befallen themselves and their dwelling-place during a few generations, it was but natural to repeat: "The thing that hath been, it is that which shall be: and that which is done is that which shall be done: and there is no new thing under the sun."[1] But we of to-day are in a different case. The

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[1] Ecclesiastes i, 9.

astronomer joining camera to telescope brings to proof in unexpected fashion that the first act in the cosmical drama, like the last, conforms to the law of derivation, that the universe exhibits in its totality the same rule of descent with modification which the naturalist observes in the moth, or the botanist in the field of wheat. The latest nebular photographs display a continuous series of gradations from the most attenuated wisps of matter to stellar spheres which bear evidence of having been newly ushered into life. " In a forest," said a great astronomer, Sir William Herschel, " we see around us trees in every stage of their life-history. There are the seedlings just bursting from the acorn, the sturdy oaks in their full vigour, those also that are old and near decay, and the prostrate trunks of the dead." Much the same succession in the stages of cosmic life are disclosed by the camera, and Evolution stands forth confirmed as true not only of every branch of the tree of life, but of nature as the sum of all things.

Nearly three hundred years ago George Herbert could say:

Nothing hath got so far
But man hath caught and kept it as his prey.
His eyes dismount the highest star,
He is in little all the sphere.
Herbs gladly cure our flesh, because that they
Find their acquaintance there.

At the close of the nineteenth century his insight receives confirmation on every hand. We learn with wonder that the scope of life on land and sea, the architecture of the forest, the ocean and the plain, with all their myriad tenantry, are what they are because the atoms which built them were present, and in such and such proportions, in the birth-cloud of the world. If a rose has tints of incomparable beauty, they are conferred by elements thence derived, whose kin, aflame in an orb a celestial diameter away, send forth the beam needful to reveal that beauty. Were the sun less rich in variety of fuel than it is, the earth, despite its own diversity of substance, would be vastly less a feast for the eye than that newly spread before us at every dawn.

When we remember how disinterested was the quest which has led to so great and unexpected knowledge, we begin to see that the philosopher is often, and unwittingly, the chiefest prospector and the best. It is doubtful whether any path of discovery whatever, no matter how unrelated to utility it may seem, can be pursued without leading to gain at last. No study would at the first glance appear to be more remote from influence upon human thought and feeling than the portrayal of heavenly bodies too distant for telescopic view. Yet that portrayal has served to enlarge our conceptions of the varied forms which worlds and suns may display; the shimmer of the nebulæ enters the camera to corroborate the story of the rock, the plant, and the animal, as each tells us how it came to be. Adding to vision the eye of artifice, we are confirmed in the faith that nature is intelligible to her inmost heart, as naught else than the expression of reason, which, infinite itself, has implanted in the mind of man an undying desire to understand of the infinite all it may.

CHAPTER XXIV

PHOTOGRAPHY AND ELECTRICITY AS ALLIES

ELECTRICITY, as we have seen, has been a most prolific parent in the field of art; scarcely less fertile have been the applications of the camera. Each of them in reaching out for alliances has entered the province of the other, with the result that the world's progress in both science and art has received a powerful impetus from instruments at once electrical and photographic. Let us first of all note their exploration of those breadths of the spectrum so long unsuspected by the investigator, and now steadily extending to many times the area directly visible to the eye. A layman would suppose that the endeavours of physicists to lengthen out the visible spectrum would cease with the very considerable additions due to the direct photography of rays ultra-violet and ultra-red. But the lay mind knows little of the persistence and address of the accomplished physicist, and can only marvel at the mode in which he summons fresh resources from points of the compass at first seeming the farthest removed from his task.

The Bolometer.

In Chapter VIII it was said that extremely minute variations of temperature are detected by a galvanometer attached to a thermopile. Professor S. P. Langley, secretary of the Smithsonian Institution at Washington, has

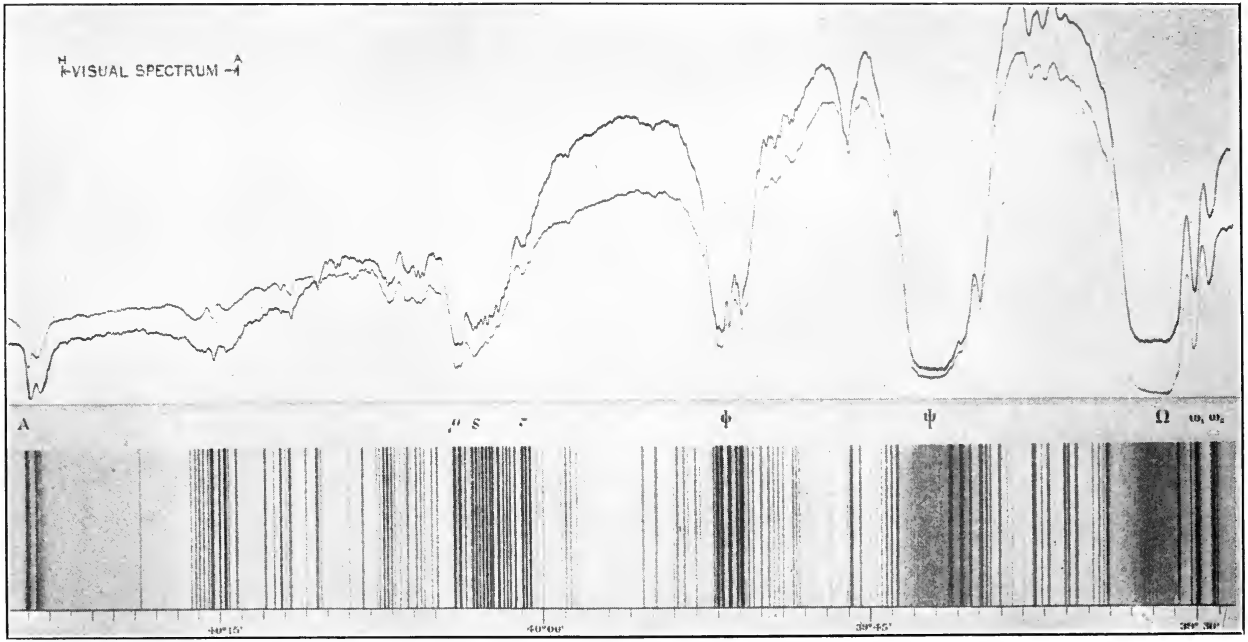

Plate XXI.

A Part of the Solar Spectrum as Extended beyond the Directly Visible Range by the Bolometer.

refined this instrument into an appliance which he styles the bolometer. Its delicate wire, much thinner than a human hair, through which an electric current constantly passes, and sensitive to much less than the ten-millionth of a degree Centigrade, is moved by minute steps through the invisible areas of the solar spectrum; each indication of temperature, automatically photographed, comes out as a line which varies in depth of tone with the intensity of the thermal ray. When the device has finished its journey the larger part of the whole breadth of solar radiation rises to view—in all fifteen times as extensive as the spectrum which Newton saw. Plate XXI represents the infra-red spectrum of a rock-salt prism, in its wave-lengths 0.75 μ to 2.29 μ.[1]

The bolometer, employed with each chemical element, promises that one day the physicist shall have before him a full, or at least a tolerably complete, map of every distinctive spectrum. He can then ask, Given such and such vibrations, how is the body constituted that sent them forth?—much as a musician might try to reason from the tone and timbre of a note to the structure of the instrument that uttered the note. A vibrating square of metal has a different sound from a vibrating triangle, and so on with every other resonant mass of simple outline. Having ascertained the distinctive note of each, it would be easy from a given sound to say that a square, a triangle, a circle, or other simple form is in vibration. In effect, therefore, as an atom is busy spreading its spectrum before the investigator it is doing nothing else than painting its own portrait, with no small promise to the chemist, who takes compounds apart that he may learn their inner architecture, their intricate ties.

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[1] Professor Langley describes the work of the bolometer in detail in his paper on "The Astrophysical Observatory," included in *The Smithsonian Institution, 1846–96—the History of its First Half-century*, Washington, 1897.

Fresh proofs await us of the supreme rank of both electricity and photography as resources of art and science as we observe the transcendent powers evoked by their union. From this union no issue is more extraordinary, more weighty with meaning and promise, than the X-ray pictures due to Professor Wilhelm Konrad Röntgen. In these pictures he has but crowned labours which began when Sir John Herschel noticed that a peculiar blue light was diffused from a perfectly colourless solution of quinine sulphate. Professor (now Sir) George Stokes explained the phenomenon by showing that this blue light consists of vibrations originally too rapid to be visible, which are slowed down within the limits of perceptibility as they pass through the liquid. A sheet of paper moistened with a solution of quinine sulphate lends itself to a simple and striking experiment: let a spectrum be directed upon it, and the rays beyond the violet, originally invisible, shine forth with a bluish-green light.

Röntgen Rays and their Kindred.

Other substances were early observed to possess this quality, among them Devonshire fluor-spar, whence the property is called "fluorescence." Glass stained with uranium exhibits it in a remarkable degree, but in this category a rank even higher is held by platino-cyanide of barium. Fluorescence lasts only during stimulation by an impinging beam of light; cut that off and at once the shining ceases—just as in the case of an extinguished candle. There is a similar kind of glow which continues long after an exciting beam of light has been withdrawn, when the phenomena merge into phosphorescence—first studied by M. Alexandre Edmond Becquerel of Paris. If, to take a common case, a lump of calcium sulphide is exposed to the sun for a few minutes, and carried into a dark room, it maintains its glow for another minute or longer. This compound, when joined to a trace of bismuth and other ingredients, forms

Balmain's luminous paint, which has remarkable phosphorescent power. Exposed to sunshine and kept in total darkness for six weeks, it has, nevertheless, been able to fog a photographic film. Specimens of lime, after exposure to the spark of a Leyden jar, have been found to give out light when heated after having been four years in the dark. Phosphorescence and fluorescence are now found to be of the same family as the X ray and many other radiations known to us only indirectly. The single name " luminescence " is bestowed upon the whole group. What gives them peculiar interest is that all are excitable in extreme degrees by electricity of high tension.

One path of approach to the achievement of Professor Röntgen was opened by Sir John Herschel; another, as important, was blazed and broadened by Professor (now Sir) William Crookes. In 1874 and 1875 he was engaged upon the researches which gave the world the radiometer, the tiny mill whose vanes rotate with rays of light or heat. The action of this mill depends upon its being placed in a glass bulb almost vacuous. When such a bulb incloses rubies, bits of phenakite, or other suitable objects, and electrical discharges are directed upon them, they glow with the most brilliant luminescence known to art. Excited by a cathode ray, that is, a ray from the negative pole of an electrical machine, a Crookes bulb itself shines with a vivid golden green ray which reminds the onlooker of the fluorescence of earlier experiments. What a Crookes bulb is we shall see in the course of this chapter.

Year by year the list of substances excitable to luminosity in a Crookes bulb has been lengthened, and in 1894 it was the good fortune of Professor Philipp Lenard to discover a wonderful power of such a bulb. Emerging from it was a cathode ray which passed nearly as freely through a thin plate of aluminium as common sunshine does through a pane of glass (Fig. 89). Hertz had, a few years previously, discovered that metals in very thin sheets were virtually transparent (or, to use Mr. Hyndman's term, transradiable) to his electric waves. This property was found by Professor Lenard to extend to the cathode ray and in a much higher degree. Gold- and silver-foil let the rays pass through with almost undiminished intensity.

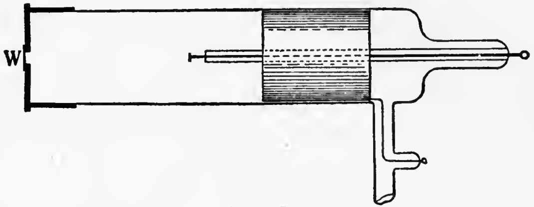

Fig. 89.
Lenard tube. *W*, aluminium window.

Especially brilliant are the fluorescent and phosphorescent effects excited by these rays; the platino-cyanides, the phosphides of the alkaline earths, calc-spar and uranium glass, are among the substances which glow brightest under their stimulus. They act with energy upon a photographic plate, over which is laid a sheet of cardboard one-eighth of an inch in thickness—this with an exposure of two minutes. The ultra-violet ray of ordinary light has the singular power of causing the gases which it may traverse to become conductors of electricity, with the effect of discharging an electrified metallic plate; this property is shared by cathode rays. Associated with them are the rays of still more extraordinary powers, discovered by Professor Röntgen. In his own words let his achievement be recounted, as published in *McClure's Magazine*, April, 1896.

> "I have been for a long time interested in the problem of the cathode rays from a vacuum tube as studied by Hertz and Lenard. I had followed their and other researches with great interest, and determined, as soon as I had the time, to make some researches of my own. This time I found at the close of last October. I had been at work for some days when I discovered something new."

"What was the date?"

"The 8th of November."

"And what was the discovery?"

"I was working with a Crookes tube covered by a shield of black cardboard. A piece of barium platino-cyanide paper lay on the bench there. I had been passing a current through the tube, and I noticed a peculiar black line across the paper."

"What of that?"

"The effect was one which could only be produced, in ordinary parlance, by the passage of light. No light could come from the tube, because the shield which covered it was impervious to any light known, even that of the electric arc."

"And what did you think?"

"I did not think; I investigated. I assumed that the effect must have come from the tube, since its character indicated that it could come from nowhere else. I tested it. In a few minutes there was no doubt about it. Rays were coming from the tube which had a luminescent effect upon the paper. I tried it successfully at greater and greater distances, even at two metres. It seemed at first a new kind of invisible light. It was clearly something new, something unrecorded."

"Is it light?"

"No."

"Is it electricity?"

"Not in any known form."

"What is it?"

"I don't know."

And the discoverer of the X rays thus stated as calmly his ignorance of their essence as has everybody else who has written on the phenomena thus far.

"Having discovered the existence of a new kind of rays, I of course began to investigate what they would do." He took up a series of cabinet-sized photographs. "It soon appeared from tests that the rays had penetrative power to a degree hitherto unknown. They penetrated paper, wood, and cloth with ease; and the thickness of the substance made no perceptible difference, within reasonable limits." He showed photographs of a box of laboratory weights of platinum, aluminium, and brass, they and the brass hinges all having been photographed from a closed box, without any indication of the box. Also a photograph of a coil of fine wire, wound on a wooden spool, the wire having been photographed and the wood omitted.

"The rays," he continued, "passed through all the metals tested, with a facility varying, roughly speaking, with the density of the metal. These phenomena I have discussed carefully in my report to the Würzburg Society, and you will find all the technical results therein stated." He showed a photograph of a small sheet of zinc. This was composed of smaller plates soldered laterally with solders of different metallic proportions. The differing lines of shadow caused by the difference in the solders were visible evidence that a new means of detecting flaws and chemical variations in metals had been found. A photograph of a compass showed the needle and dial taken through the closed brass cover. The markings of the dial were in red metallic paint, and thus interfered with the rays, and were reproduced. "Since the rays had this great penetrative power, it seemed natural that they should penetrate flesh, and so it proved in photographing the hand, as I showed you."

For twenty years before their detection the X rays had been created in experiments with the Crookes bulbs. Röntgen's great discovery was no accident. He was at the time studying the phenomena of luminescence, as well as those of electricity pure and simple; this accounts for his having at hand the telltale screen of barium platino-cyanide, which showed the peculiar black streak, excitable only by rays of known or unknown species. Without the trained intelligence to observe an unusual phenomenon so slight in degree, and follow it up patiently to its cause, the X rays would have fallen as vainly across his laboratory that memorable November morning as they had often before traversed the work-rooms of other investigators. As we glanced at the

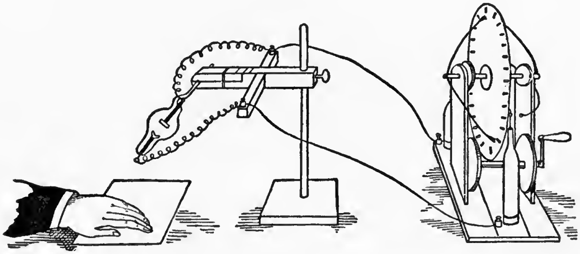

FIG. 90.
Crookes tube photographing the bones of a hand.

astronomical conquests of the camera, we saw that they declare the firmament to be not only much vaster but also more diversified in its tenantry than was supposed a generation ago. So, too, with the realm of nature near at hand. The ultra-violet ray is found to have properties more searching than those of common light; the cathode ray is discovered to be more penetrating still; and partnered with it is a distinct emission which casts shadows of bone through solid flesh, of gold or lead through a wooden coffer. It is this outdoing of the beam studied by Lenard that so quickly gave the X ray its world-wide fame (Fig. 90).

The photographer, like the draughtsman, had long been content to delineate surfaces solely. It is only the rare talent of an Alma-Tadema that can simulate translucency with the brush, and cozen the eye into believing that it peers below the glinting of a marble fountain or a wall. Provided with a Röntgen bulb, the photographer passes from the exterior to the interior of an object, almost as if he were a sorcerer with power to transmute all things to glass. Equipped with a simple X-ray apparatus, dislocations and fractures are detected by the surgeon, diseases of bones are studied, and shot, needles, and bits of glass or corroding wire within the muscles of a patient are located with exactitude. Thanks to the work of Mr. Mackenzie Davidson, the like detection of renal calculi can be looked forward to with a fair degree of certainty. The same means of exploration offers equal aid to medicine: it demonstrates the calcification of arteries, and aneurisms of the heart or of the first part of the aorta; with improved methods it may be possible to study fatty degenerations of the arteries and larger blood-vessels. Dr. C. M. Mouillin, addressing the Röntgen Society of London as its president, states that the fluorescent screen has now reached such a degree of perfection that the minutest movement of the heart and lungs, and the least change in the action of the diaphragm, can be watched and studied at leisure in the living subject. He considers it probable that the examination of a patient's chest with this screen may become as much a matter of common routine as with the stethoscope to-day. A forecast more recent still points to the possibility of committing X-ray impressions to kinetographic films, this with intent to further the resources of medical instruction.

Scanned by this new detecter, the dead as well as the living tell their secrets. In the Museum of Natural History at Vienna there is an Egyptian mummy which is human in form, but which from its inscriptions was taken to be that of an ibis. It is, however, so rare and valuable an object that it was not thought advisable to quiet doubts by removing its wrappings—with the inevitable risk of damage. On being subjected to the X rays the mummy disclosed the unquestionable outlines of a large ibis-like skeleton.

An extension of the utility of X rays would seem to lie in employing extreme electrical pressures and the closest possible approach to a perfect vacuum in the bulb. Professor John Trowbridge has found that with 3,000,000 volts a single discharge through highly rarefied media produces X rays powerful enough to photograph the bones of the hand in one-millionth of a second. In the operative surgery and medicine of the nineteenth century the X rays take a place of honour side by side with anæsthesia and the antiseptic treatment due to Pasteur and Lister. In the study of the phenomena of growth these rays are informing in a new way. Pigs and other domestic animals have been photographed day by day from birth, clearly showing the result of various courses of feeding on the formation of flesh and bone. In a totally distinct field of inquiry, X rays are employed to detect slate and other admixtures in coal.

Slate is comparatively opaque and coal transparent to these impulses.

Other Luminescence.

Professor Röntgen's success has spun a thread which unites many researches in contiguous fields. In 1896 M. Henri Becquerel and Professor Silvanus P. Thompson independently found that certain salts of uranium—for example, the nitrate of uranyl and the fluoride of uranium and ammonium—emit invisible radiations which easily pass through aluminium and produce on a photographic plate images of interposed objects comparatively opaque. This effect, says Professor Thompson, "appears to be due to an invisible phosphorescence of a persistent sort." Some time afterward M. Becquerel observed that uranium by itself far surpasses any of its compounds in this weird property, emitting rays continuously and with apparently undiminished intensity for more than a year.

In 1898 and 1899 M. and Mme. Curie announced their discovery in pitch-blende of two new substances, radium and polonium, both having much greater radioactivity than uranium. Dr. W. J. Russell, of the Davy-Faraday Laboratory, London, has greatly extended the study of rays not directly visible. He has observed photographic effects from bright zinc, from wood, charcoal, and paper; all of which seem to be due to the formation of peroxide of hydrogen during the photographic process. So active is this peroxide that one part diluted with a million parts of water is capable of giving a picture. With rays emitted by sugar, after they had pierced a block of wood two and a half inches thick, Mr. A. F. McKissick has photographed coins, keys, and pieces of glass. So far as known at present, there are neither Röntgen nor Becquerel rays in sunlight, but M. Gustave le Bon has shown that the solar beam has a power of permeation somewhat allied to the Röntgen and Becquerel phenomena. He finds that if sunshine falls upon a thin sheet of iron covering a negative and a sensitive plate, the plate gives a normal though weak positive on development.[1]

The Unseen Universe.

Manifestly, the unseen universe which enfolds us is steadily being brought to the light of day. The investigations of Hertz established that the light-waves which affect the eye are but one octave in a gamut which sweeps indefinitely far both above and below them. In his hands, as in those of Joseph Henry long before, electric waves found their way through the walls and floors of a house; in the Marconi telegraph these waves pass through the earth or a fog, a mist or a rain-storm, with little or no hindrance. What does all this mean? Nothing less than that, given its accordant ray, any substance whatever is permeable, and that, therefore, to communicate between any two places in the universe is simply a question of providing the right means. And limited in range though the visual faculty of man may be, he is fast ascertaining how to treat an invisible ray so as to bring its image to view. If the wave in its original path eludes his eye, it cannot strike his photographic plate without leaving its impress—to be examined at leisure. In photographic chemistry enough has been done to make it entirely probable that no ray undulates through space that is not matched by some compound or other which it has power to shake apart. Small and feeble though the hand of man may be, it yet holds clues to every maze in the universe—clues through which the unseen may be perceived, the silent given a voice, the impalpable rise to touch. The day seems at hand when every undulation of heat and sound, with all the waves in-

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[1] Much interesting detail is recorded in *Light, Visible and Invisible*, by Silvanus P. Thompson, London and New York, Macmillan, 1897; in *Radiation*, by H. H. F. Hyndman, London, Sonnenschein, and New York, Macmillan, 1898; also in appendices to *Signalling Without Wires*, by Oliver J. Lodge, third edition, London, The *Electrician* Co., 1900.

termediate and beyond, will depict themselves for studious investigation.

The Intruder is a Friend.

And let it not be forgotten that these revelations took their rise in what was at first resented as an intrusion. When the ultra-violet ray impressed itself upon the earliest photographic plates it so seriously deranged the translation of colour that, if possible, the photographer would have banished it at once and forever. Yet that intruding ray has proved to be a friend, not only generous in gifts of its own, but pointing to other and greater wealth fast being won from darkness to light. When the solar spectrum is thrown upon a sensitive plate it is in the violet and ultra-violet region that the principal change occurs. It is in asking, What more? that so much has been rescued from the Unknown, not only within the play of the spectrum of the sun, but also in spheres of radiation that seem to have little or nothing in common with the solar beam.

Again recurs the truth that no property of matter exists, though at first it may seem merely strange and useless, but holds the richest meaning for the explorer. For a good many years the examination of fluorescent substances might have seemed futile enough. What is the good, the practical man might have asked, of showing me the bluish light into which you convert rays otherwise unseen? Professor Röntgen has answered that question, and the vast field of research in which he is the most conspicuous figure may bear harvests quite as rich as his in the early years of the twentieth century. We have learned that light may be freely radiated without the company of heat—as in the familiar gleam of the glow-worm and the firefly. Is it too much to expect that art will pursue nature to yet another fastness, and so economically create light in her own method that the gross waste of the electric lamps of to-day may soon cease to reproach the physicist?

But let us descend from these high anticipations to unions of electric and photographic art already accomplished and highly fruitful. In places inaccessible to daylight, and anywhere at night, the electric beam, instead of the sun, is at the camera's service. In 1890 a landslide took place at Chancelade, in France, overwhelming a quarry in which labourers were at work. Fortunately a chink remained in the rock and rubbish, which, small as it was, admitted a camera with its electric lamp and wire. Informed by its pictures, the imprisoned men were traced and speedily rescued. To pass from help in accident to aid in disease: Dr. Edward O. Schaaf of Newark, New Jersey, in 1897, devised a camera and lamp by which he has repeatedly photographed small areas of the mucous membrane of the stomach, a branch of diagnosis in which progress is also reported from Germany.

Union of the Camera and the Electric Lamp.

The independence of air enjoyed by the electric light bestows upon the sensitive plate the freedom of the ocean depths, or admits it to mines vitiated by fire-damp beyond the endurance of human lungs. In surveying the river beds from which the piers of bridges are to rise, and the surf-swept beaches on which telegraph cables are to be laid, the electric lamp and its twin, the camera, are becoming indispensable to the engineer. The perfect mechanical control introduced by electricity enables a war-time photographer, at the safe end of a wire, to send his camera aloft under a balloon or a kite, effectively playing the spy. In a registry which commenced in purely scientific curiosity, and which to-day serves not only the astronomer but the forecaster of weather, a luminous beam is a pencil without weight which records from instant to instant variations in magnetic dip and inclination, the electrical condition of the air, the force and direction of the oscillations which herald or accompany an earthquake. In its simplest form this kind of apparatus is a cylinder of sensitised paper which performs a revolution in twenty-four hours. A dot of light streaming from a fluctuating instrument is constantly writing on the sensitive surface of the paper the path or the pressure to be recorded.

A simple automatic recorder of earthquakes might once have saved Australia from alarm bordering on panic. One night, a few years ago, all the three cables uniting that country with the rest of the world suddenly parted. As there was on land no perceptible shock of earthquake, the disaster was suspected to be the work of an invading foe. The troops were immediately placed under arms, and with energy and haste all the machinery of resistance was overhauled and made ready. All this was needless, for it was soon ascertained that the ocean bed adjoining the continent had suddenly moved just enough to break the cables and do no further damage. Because an instrument of ordinary delicacy was lacking to register this simple fact, some three million souls saw reason to dread an armed invader.

At the close of Chapter XIV we noted the exquisite apparatus which writes in ink a cable message as it issues from beneath the sea. An electric impulse even feebler may be recorded photographically as it sways a receiving-needle. This feat may play a part in cheapening the cable soon to be laid across the Pacific—for a distance longer than has yet been attempted by the telegraphic engineer.

The Personal Equation and its Remedy.

Astronomers in their direct use of the eye are troubled by "the personal equation," such as the observer's anticipation or delay in noting the instant of a phenomenon. To eliminate this source of error is the purpose of an invention by the Rev. George A. Fargis, of the Georgetown Observatory in Washington. An electrically driven clock moves a sensitised sheet of paper, catching the image of a star at the instant of its passage across the wires of a telescope—the time of transit being simultaneously recorded (Fig. 91). In a widely remote sphere, that of animal movement, mention has been made of Mr. Muybridge's remarkable pictures. It was only by having electrical control of his cameras that those pictures were secured. There are motions swifter still to be depicted, but none of them so swift as to elude the sensitive plate. Turning upon its ally electricity, it makes plain its most devious paths, its most abrupt discharges. Lightning, natural and artificial, in every phase, has left its imprint in the camera (Plate XXII).

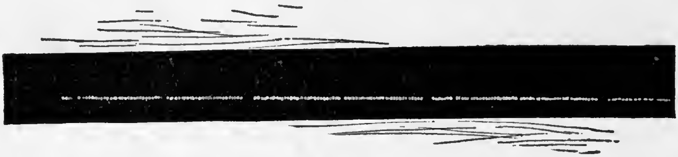

FIG. 91.
Fargis recorder.

The Photography of Sound.

The phenomena of sound, less exacting in point of time, have, of course, not evaded the photographer. Dr. Raps of Berlin has pictured the vibrations of an organ pipe, of a hunting-horn, as well as the singing of the vowels. Professor Boltzmann, and other investigators of mark, have depicted the complex curves of the telephone in oscillations as rapid as 3000 in a second. At the London Exhibition of 1862 Rudolph Koenig made public his beautiful drawings of flames, excited to sympathy with sounds. From the difficulty of following so great a master of the pencil as he, his method was little cultivated by men of research. By good fortune, the motion of flame as it rises and falls under the impact of sound is, comparatively speaking, slow; thus one of the first phenomena to be observed by primitive man lends itself to the most modern methods of

By H. A. Beasley, Walbrook, Baltimore, Maryland.

Plate XXII. *From the Photographic Times, January, 1900.*

By J. H. Dunn, New York.

PHOTOGRAPHS OF LIGHTNING.

depiction. A photographic plate is moved behind the lens of a camera at such a rate that during each vibration of a flame the plate advances by a space at least twice as great as the width of the flame. With such an apparatus Professor Ernest Merritt of Cornell University, in 1893, found it just possible to photograph the flames delineated by Koenig.[1] In 1897, jointly with Professor Edward F. Nichols, he used an improved camera, with acetylene as an illuminant instead of common gas. The photographs were now defined much better than those of four years before. Professor Nichols says:

> When we attempt to read such a record, as one would read the trace of the siphon recorder in a telegraphic message, or as one would read shorthand, we find that it is only the vowels that produce any marked agitation of the flame. All those accompanying mouth sounds which introduce and close each syllable in articulate speech, and by which, in great measure, we are able to distinguish the different words, produce a very feeble and often an unrecognisable effect upon the flame. The records are indeed the very opposite of shorthand writing, not only that instead of a single character to a syllable we have sometimes as many as a hundred oscillations of the flame, but likewise in the fact that while shorthand is made up of words with the vowels left out, these photographs represent speech with the consonants suppressed. . . . Not only are the subtile differences which distinguish the vowel sounds uttered by persons speaking various dialects manifested by differences in the flame groupings, but the individual peculiarities in the utterance of different speakers using the same dialect are plainly discernible (Fig. 92).[2]

FIG. 92.

The sound of *A flat* photographed from a manometric flame.

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[1] *Physical Review*, Vol. I, p. 166.

[2] *Nature*, Vol. LIX, p. 321.

If it ever becomes possible to decipher this sound-script we shall come to the same goal as that of the phonograph —and by a very different path.

Time Infinitesimal.

Photography with a plate in swift motion is one of the most searching instruments of exploration at the physicist's command. All that the astronomer and the meteorologist accomplish with a sensitive plate is carried to a new scene when the telltale changes in the strength of a current are caught in minute subdivisions of time. A curve-writing volt-meter may be made to give records on a moving plate running to within the thousandth of a second of the instant when such a process as electrolysis, electrolytic polarisation, voltaic action, or the charge or discharge of a condenser begins.[1] Now that electricity and photography march forward in the same yoke, they promise us insights of superlative importance. It is what occurs in less than the twinkling of an eye, the effects of contact, the unions and partings of molecules, that most concern the modern inquirers in the fields of physics and chemistry. If these phenomena are ever imaged upon photographic films, investigators will possess no merely curious pictures, but plain hints for the further extension of human sway over both matter and motion.

The Eye of Art far Transcends the Eye of Nature.

We have now come to the end of our hasty review of the principal feats of photography in its aid to science, art, and literature—in its furtherance, not unimportant, of new recreation. If electricity in the nineteenth century has advanced art and science by leaps and bounds, hardly less decisive is the impulse due to its sister force, light, as a universal limner and explorer. The first

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[1] Address on the "Phenomena of the Time Infinitesimal," by Professor E. L. Nichols before Section B,—physics,—American Association for the Advancement of Science, 1893.

tasks of the photographer lay in creating a plate which should approach as nearly as possible to the powers of the eye and the hand—in true representation of form, of colour, of relief, of motion. His later work is crowned by the production of plates which far transcend the capability of vision in being quicker, more persistent, and in having a susceptibility to rays which fall upon the retina only to prove it blind; while every impression becomes as permanent as ink can make it. Thus the most exquisite of all the senses is enlarged in scope as no other is, or ever may be. The modern camera, moreover, lends itself to forms of reproduction totally new in their verity, beauty, and cheapness, so that the photographer has ushered in nothing less than the democracy of art. While he brings many an ancient aptitude to a new fruitfulness, he also creates a thousand novel modes of attack upon the infinite Unknown.

CHAPTER XXV

LANGUAGE

Much to See, Little to Hear.

THAT our ancestors were capital draughtsmen long before they came to articulate speech is probable from the extreme antiquity of excellent pictures, and from abundant proof that spoken language is a comparatively recent acquisition. Why the art of the depicter may have long preceded that of the speaker we can easily understand. Let us ask a primitive wanderer to live over again a day of his life for us, and the reason will be sunshine clear. As he roams about from dawn to dusk in quest of food he passes from thicket to plain, from plain to swamp, from swamp to sea-shore—with all their variety of changing scenes. Here he catches a glimpse of a bunch of alluring grapes, there he sees a bush laden with nuts, anon he detects the spreading leaves which betoken a root easily dug from the beach—and all the livelong day hardly once does the man hear a sound that bears him a message. If a cricket chirps what matters it to him? If a bird trills a few notes, the roulade is addressed, not to his ears, but to those of its mate. Such beasts of prey as lurk in the tall grasses of the swamp, or in the underbrush of the woods, find their account in a tread of the stealthiest, in a silence rarely broken except at the season of espousal. It is not in listening for a grunt, or a yelp, so much as in watching for a telltale footprint, that the man keeps himself safe from these foes. And hence, because his livelihood and his life depend almost wholly upon his sight, and scarcely at all upon his hearing, his eyes concern themselves with the art of representation long before his ears take part in the work of bringing the absent into the here, and making the past re-transact itself in the now.[1]

In Chapter XIX we endeavoured to recall some of the principal steps by which the modeller and the depicter began their tasks. The free and skilful hand, indispensable to both those artists, did much more early in the human day than mould the clay for a rude effigy, or draw in sand the profile of a chief. Dogs and ants, together with many brutes and insects much less intelligent, can give signals which mean, "Come with me," but the hand of a primitive fire-kindler as it pointed to a dwindling blaze, and then to the forest whence a junior was desired to fetch more fuel, could signify, "Go," a message often of much more consequence, and a message to which the mere brute has never risen. In like manner a primitive mother could show her young the berries or the nuts so much hidden by leaves on a distant bush as to elude the little ones' gaze; or a sentinel with the safety of silence could point out to his companions the crouching tiger otherwise unseen. His simple gesture said "tiger" almost as plainly as when to-day a visitor to a zoological garden utters the word. That there is a close correspondence between the infancy of the race and that of a modern child every cradle bears

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[1] A question which might well engage the thought of a musical scholar is, Why is great music so recent? Why did Bach, Beethoven, and Wagner follow so long after Phidias and Praxiteles, and the inventors of the five orders of classical architecture? Does part of the explanation reside in the fact that for ages there was more for man to see than to hear, so that the cultivation of hearing lingered after that of vision? For æons the eye could "dismount the highest star," while the ear had not heard its chief message—the word—because human lips were still to be unsealed.

witness. Weeks before a babe can say a syllable, ask it, "Where is mama?" and the little eyes and hands may move forward in the reply, "There."

From the beginning man must have had in common with other animals some powers of vocal expression, and more ample than theirs because he had more to express. His cries at first probably denoted the simplest and strongest appetites and feelings,—hunger, pain, rage, and the like,—rising in due time to a chatter such as that by which existing anthropoids signify comfort, greetings, endearment. Professor Shaler has remarked how much more varied and expressive are the voices of dogs reared for generations by civilised men than the few and simple barkings of dogs in the camps of savages.[1] One of the decisive characteristics of the race now human consists in its faculty of imitation, and this must have early borne a part in enlarging the utterances of man. We have noted how at the outset of graphic representation the limner imitated the profile of a human head, or the contour of a horse. Long afterward the simulation of sounds was to play an equally important rôle in leading to language by an appeal to the ear instead of to the eye. In one case as in the other the beginnings may have been matters of sheer sport. In rearing lambs, and the young foxes and wolves from which dogs may be descended, there was an incitement to imitate bleating and snarling, especially on the part of children. Proficiency in this art could easily extend itself to repeating the utterances of beasts of prey. The talent which began in sketching the outline of a bear came to a rightful succession when a mimic amused himself in echoing the growl of the beast. Suppose such a mimic to be a watcher on the lookout from the topmost branch of an oak. He detects in the distance the ambling figure of a bear. His

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[1] *Domesticated Animals, Their Relation to Man and to His Advancement in Civilisation*, by N. S. Shaler. New York, Scribner, 1895.

comrades to whom he points out the animal fail to descry it. He imitates the growl of the slinking brute—at once his comrades know what to look for. They turn their eyes from the trees to the ground and see the bear distinctly.

The Naming Faculty.

Here emerges the naming faculty unshared by man with any other creature. Many animals utter cries of alarm, but the sentinel with wit enough to mimic a cry so as to indicate the beast which utters that cry has taken a leap which divides him and his race forever from animals expert enough in mere warning or mimicry, but lacking the intelligence which impresses sounds into a means of naming. Uncounted species high and low in the scale of life are able to utter the wail of pain, the whine of fear; man alone can plainly tell what has caused his pain, what excites his dread. New avenues of escape from danger, new means of advantage, and new sources of social cheer, came to men so soon as they could utter a name, in however imperfect a fashion. Here the language of the hand began to be supplemented in the most useful way, and in many cases altogether replaced. To quote Professor Whitney: "The voice is on the whole the most available means of communication. It acts with the least expenditure of effort. It leaves the hands, much more variously efficient and hard-worked members, at leisure for other work at the same time; and it most easily compels attention from any direction."[1] A scout, invisible in darkness, fog, or tempest, could now easily bid his fellows find their way to a cave, or warn them to avoid a clump of trees where a foe lurked in ambush.

Alliances between gesture and speech, between mimicry and names, which date back to the very birth of human language, have their reminders before us at this hour. An orator recounts the details of a shipwreck in which he was a

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[1] *Life and Growth of Language*, International Scientific Series, p. 293.

sufferer—and his hands are only less eloquent than his tongue. A child points to a cow in its pasture and says, "Moo-moo," by way of a name. When the little one comes to town from its home in the country it tells how a locomotive was its carrier by saying, "Shoo-shoo," and turning its arms in imitation of the engine's revolving wheels. We speak of the "cuckoo," the "peetweet," the "whip-poorwill," the "katydid," in names which they themselves have suggested to us. Hundreds of other common terms—"crackle," "sizzle," "buzz," "whir," and the like—testify every day to the debt that sense owes to sound, to the important contribution by onomatopœia to the mintage of words. Another well-spring of speech deserves a moment's heed. A few syllabic sounds mount of themselves to the lips of a babe, and these, at first by their seniors, are taken to mean definite persons and things. Sir John Lubbock has ascertained that "pa" and "ma" are among the very first because the easiest utterances of a child; and "pa" and "ma" have long been appropriated by parents to signify themselves. All young children have difficulty in repeating their own names; for months Stella may call herself "Cally," and George may say that he is "Joe," simply because their powers of articulation are but little developed. By reducing the long words of their elders to pronounceable form, and by downright invention,—based upon spontaneous sounds,—children have been known to devise long vocabularies for themselves. In so doing they have undoubtedly shed light on one of the methods by which early speech began.

Spontaneous Utterance.

When primitive man had advanced somewhat in the faculty of naming we can imagine him passing from things to the qualities of things. Terms such as "warm," "cold," "wet," "dry," "long," "short," would spring to his lips—at first perhaps connected with the objects usually pre-

The Adjective and the Verb.

senting a specific quality in a striking degree. In common parlance to-day we speak of a thing "as dry as a bone," or "as cold as ice." When a deaf-mute wishes to signify "red" he protrudes his tongue and touches it with his finger.[1] In the language of gesture the arms are slightly bent and rapidly flapped to mean "bird"; but the same sign has to serve for "flight," or "flying," and which of the three meanings is intended to be conveyed must be judged by the onlooker from the rest of the story. Early in the formation of articulate speech there must have been the setting apart a sound to signify what a person or a thing does, in addition to what the person or thing is; the verb was created in succession to the adjective and the noun. Then slowly from the adjective and the verb there arose the power to name such conceptions as "good" and "right," which end at last in the highly abstract terms of the man of science, the philosopher, the metaphysician. There was inestimable gain in the steadily growing power to symbolise by sounds as well as by graphic delineation. Ideas became more tenacious when they were rooted in the memory both through the ear and the eye—as every student discovers anew when he learns a foreign tongue both in speech and in print. But let the art of gestural or graphic depiction rise as high as it can,

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[1] In its achievement of lip-reading the art of communication returns in most ingenious fashion to something of its first estate. As the ages of human progress have succeeded each other, the misfortune of deafness has meant more and more of deprivation. For the aid of the deaf-mute an elaborate code of manual and gestural signs was long ago contrived. It has been the life-work of Professor Alexander Melville Bell and other eminent teachers virtually to unstop deaf ears, and unloosen the tongues of the dumb by a happy and original impressment of sight. The system is based upon the close observation of the moving lips of a speaker, whose words are known through the slight and wholly incidental movements which accompany their utterance. Then, to supplement this hearing by the eye, the lips of the dumb are patiently instructed to imitate the motions of speech, with the effect of distinct articulation.

it soon comes to rigid limits only to be overpassed by vocal utterance. What scheme of manual signs could interpret Kant's *Critique of Pure Reason*, or Herbert Spencer's *First Principles*? So profound are the obligations of thought to language that Professor Max Müller maintains that thought and language are identical. He says: "Words without thought are dead sounds; thoughts without words are nothing; to think is to speak low, to speak is to think aloud."[1] Another eminent philologist, Wilhelm Bleek, has said:

> It is through language and by language that man, as a thinking being, has developed himself. It is communication by means of speech that brings his thinking to greater clearness, by bringing the different modes of thought into mutual furthering communication with each other. By means of speech man is able to hold with more tenacity the impressions already obtained, and thus better to combine the old with those whose action is fresher, and generally each with every other, and to work them up into intuition. It is the spring of self-consciousness inasmuch as it enables man to distinguish himself and his emotions from the external world, and so to become conscious of both. Thus it is only by means of it that true development of thought can take place. Wilhelm von Humboldt said in his last letter to Goethe: "The entire possession of ideas is just what we, placed outside of ourselves, can cause to pass over into others."[2]

Professor William D. Whitney, the foremost American philologist of his time, tells us:

> It is not easy to estimate the advantage won by the mind in the obtaining of a language. Its confused impressions are thus reduced to order, brought under the distinct review of consciousness, and within reach of reflection; an apparatus is provided with which it can work like an artisan with his tools. . . . By as much as, supplied with tools, man can traverse space, handle and shape materials, frame textures, penetrate distance, observe the minute, beyond what he could compass with his unequipped physical

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[1] *Science of Language*, Vol. I, p. 527. London and New York, 1891. For a criticism, see *Max Müller and the Science of Language*, p. 26, by W. D. Whitney. New York, Appleton, 1892.

[2] *On the Origin of Language*, p. 43. Translated by Thomas Davidson. London and New York, 1869.

powers, by so much is the reach and grasp, the penetration and accuracy, of his thought increased by speech. This part of the value of speech is by no means easy to bring to full realisation, because our minds are so used to working by and through words that they cannot even conceive of the plight they would be in if deprived of such helps. But we may think, for example, of what the mathematician would be without figures and symbols.[1]

With this dictum of Professor Whitney's in mind, let us try to add together ten lines, each bearing a number expressed in ten Roman numerals. The feat is all but impossible; reduce the numbers to the Arabic notation and the task at once melts to a trifle. Thus does a simple and adequate symbolism promote the science and art of number. In that larger field of expression, language, the ability to denote general ideas by words has been a transcendent means of multiplying such ideas; these more conclusively than ever have withdrawn man, the thinker, the abstract reasoner, from the lowly stock which remained inarticulate when he arrived at speech. Physiologists of authority are in accord as to the extreme demands which language makes upon the powers of the brain. Nothing, they tell us, has done so much to increase cerebral weight and complexity as the development of articulate speech. It is, indeed, that development which accounts for the largeness of brain which is distinctive of man. By way of prefacing a consideration of this point, let us note three of the most remarkable human skulls thus far unearthed.

Three Notable Skulls.

Among human fossils the most remarkable skulls are those, first, of the Cro-Magnon race of neolithic France; second, the Neanderthal cranium found near Düsseldorf; and third, that of *Pithecanthropus erectus*, discovered by Dr. Eugene Dubois in Java. In size and form the Cro-Magnon skulls denote that their possessors were men of remarkable intelligence, a view corroborated by the etchings on bone,

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[1] *Life and Growth of Language*, p. 23. International Scientific Series.

wrought by these primitive artists, and found near their remains. Concerning the Neanderthal cranium, Professor Huxley said in *Man's Place in Nature:*

> Under whatever aspect we view this cranium, whether we regard its vertical depression, the enormous thickness of its supraciliary ridges, its sloping occiput, or its long and straight squamosal suture, we meet with ape-like characters, stamping it as the most pithecoid of human crania yet discovered.

This was said in 1860. Thirty-four years later Dr. Dubois discovered the famous skull of *Pithecanthropus erectus* in Java. The next year, in 1895, at the International Zoological Congress, in Leyden, this skull, with the other remains found with it, were discussed by twelve experts. Three held them to belong to a low race of man; three declared them to be those of a man-like ape of great size; the rest maintained that they belonged to an intermediate form which directly connected primitive man with the anthropoid apes. "This last view," says Professor Haeckel, "is the right one, and accords with the laws of logical inference. *Pithecanthropus erectus* is truly a Pliocene remainder of that famous group of highest catarrhines which were the immediate pithecoid ancestors of man."[1]

A Leap due to Language.

And now let us listen to an ethnologist of eminence who devoted his life to the study of language. At the meeting of the American Association for the Advancement of Science in 1886, Mr. Horatio Hale delivered an address "On the Origin of Languages and the Antiquity of Speaking Man." In the course of a review which summed up convictions due to a lifetime of research, and which he supported by much detailed evidence, he said:

> It is impossible to suppose that a people possessing the intellectual endowments of the Cro-Magnon race would long remain

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[1] *The Last Link.* London, Adam & Charles Black; New York, Macmillan & Co., 1898.

in an uncivilised state, if they were once placed in a country where the climate and other surroundings were favourable to the increase of population and to improvement in the arts of life. Even in the then rigorous climate and other hard conditions of western Europe, they had advanced, as Dr. Paul Broca declares, "to the very threshold of civilisation." What must they have become in Egypt and in southern Asia? In point of fact, during a comparatively brief space of time, ranging from five thousand to seven thousand years ago, the men of these regions developed in widely distant centres—in Egypt, in Mesopotamia, in Phœnicia, in northern India, and in China—a high and varied civilisation and culture, whose memorials, in their works of art and their literature, astonish us at this day, and in some respects defy imitation. To what circumstance can we attribute this sudden and wonderful flowering of human genius, after countless ages of torpidity, but to the one all-sufficient cause—the acquisition of the power of speech?

The particular impetus here may have lain in the mastery not only of some decisive access in articulate speech, but in a transition from mere portraiture to narrative picturing, such as the pictographs of the North American Indians collected and interpreted by the late Colonel Garrick Mallery.[1] By such a step forward records of a new significance and permanence might see the light. Knowledge which before had died away in mere vocal utterance, or observed gesture, could now be graphically perpetuated; at a stroke the casualties of oral tradition might begin to disappear. As writing gradually emerged from hieroglyphics and pictographs there was advance in the great art by which knowledge was accumulated, and the experiences of the boldest, and the thoughts of the wisest, were placed at the service of their brethren far distant in both place and time.

The later steps of the development of language have been in its graphic forms and are plainly within the purview of the student; because they directly illustrate permuta-

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[1] First, Fourth, and Tenth Annual Reports, United States Bureau of Ethnology, Washington.

tion they give a new warrant to the arguments of this book. The new birth of knowledge, the revival of the spirit of inquiry unhampered by tradition, which commenced in Europe four centuries ago, has been largely indebted to the art of printing, to the re-invention of movable types by Gutenberg of Mainz. Isaac Taylor, in *The Alphabet*, Vol. II, p. 182, says:

The Leap due to Printing.

> In the fourteenth century engraved wooden blocks were used to print playing-cards and sacred pictures. The next step was to engrave a few words below the picture, as in the case of St. Christopher, with two lines of legend, dated in 1423. The revolution effected by Gutenberg consisted not so much in the printing-press as in his subsequent invention of movable types, which were first cut in intaglio, and then cast in metal from the wooden matrix. Without these types his enterprise of printing the great folio Bible. completed in 1455, would have been impracticable. Movable types, however, have been repeatedly invented. They were probably used for Babylonian and Assyrian seals, and were undoubtedly employed long before the Christian era by the potters of Thasos, as is proved by the occasional inversion of potters' marks. They were again invented in China in the tenth century A. D., and were also used about the same time for stamping the legends on the coins of Tibet.

The essence of this great invention lay in having the types *movable*, so that each might be an element in that permutation of letters which we call a word.

Long before the making of such types the same principle had been arrived at in the alphabet—certainly the most extraordinary and influential achievement in the history of human expression. It appears to have been attained by a series of small adaptations, one after another, at the hands of men who did not foresee the surpassing importance of labours which, indeed, were more in the nature of unintended discovery than of deliberate contrivance. The alphabet took its rise in picture-writing. The picture of a thing stood for the thing, and when the picture was

Origin of the Alphabet.

seen the name of the thing was pronounced. Thus the Egyptians represented " mouth " by an outline of a mouth. Whoever saw that outline said "Rho," the Egyptian for mouth. But the sound "rho " could occur in the language with other meanings. The next step, then, was to indicate the sound "rho," whenever it was intended to mean "mouth," by the picture of a mouth, which was gradually in time conventionalised (Fig. 93). Finally the vowel was disregarded, and a picture of a mouth came to represent R, as a sound and as a written letter, under any and all circumstances. The sign which first had stood for a thing, and then for the sound of its name, was now completely detached from its original source and meaning, so as at last to signify a sound simply and only. In this way the Egyptians worked out a complete alphabet in the modern sense, but they never applied it in its purity. They retained much of picturing in their writing, apparently unaware that picturing could with advantage be wholly superseded by a sign for each of the few sounds with which all the words of a full vocabulary may be formed. It is asserted, but so far unproved, that the Phœnicians perfected the alphabetical principle which they derived from the Egyptians. At last, by whomsoever accomplished, the letters which formed the elements of names, or other words, became so simple that, few though they were, they sufficed to build the amplest speech. That language may be considered as jointed, that its joints are separable, and that, for all their fewness, they may yield permutations in myriads, is surely as pregnant a discovery as ever has fallen to the lot of man. In modern English 26 letters produce no fewer than 250,000 words in an exhaustive dictionary which includes technical terms. The Chinese, with singular conservatism, have clung to

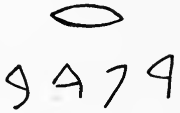

FIG. 93.
"R," from "Rho," Egyptian for " mouth," with Phœnician derived forms.

abbreviated pictures for each individual object or person, relation or idea, with the result that their written characters are nearly 50,000 in number. Incomparably better is the plan which constructs a word from its simplest component sounds, and gives each of these sounds a sign easily written or printed. Professor A. Melville Bell, in his *Visible Speech and Vocal Physiology*, and also in his *World-English*, has pointed out the shortcomings of the English alphabet,—its failures to match sounds with signs,—and proposed a complete series of symbols which would shorten by as much as a year the time needed for the mastery of the English tongue.[1] The World-English alphabet consists of forty-four elements. The symbols of "visible speech" are adapted to the expression of the articulate sounds in all languages, and thus proffer themselves as the foundation of a universal tongue.

Permutations Possible and Actual.

Taking the English alphabet as it stands, if every permutation of it were pronounceable and charged with meaning, 9 of its letters would be enough to give us 362,880 words as against the 250,000 to be contained in the new Oxford Dictionary. If the whole 26 letters, from A to Z, were capable of like permutation, the product would be no fewer than 403,291,461,126,605,635,584,000,000 words. In the arrangements and rearrangements of the 10 Arabic numerals in mathematics, in the endless assemblages possible to the 88 notes of an ordinary piano, there is a much wider play of permutation than in word-making. So, too, in the sphere of chemistry, its seventy or eighty elements may be combined to form substances all but infinite in their variety; and here we come upon

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[1] These works are published by the Volta Bureau, Washington. *Visible Speech* is now employed in America in teaching six thousand deaf pupils. It is because of this particular use of the symbols in this country that their value in general education is less widely understood here than in Europe.

strange contrasts between the combining power of one element and the inertness of another. Carbon enters into so enormous a number of important compounds as to have a "chemistry" to itself, while argon and helium seem to be entirely devoid of uniting power. However numerous the compounds created from the elements of the chemist, each bears a distinct name. The dictionary has many other terms than those of the chemical laboratory, and language far excels the permutations possible to the followers of Lavoisier, for words may, in turn, be united to form statements numberless. The infinity of observation and experience, of interpretative and imaginative power, may all be told as words flow into the sentences of the explorer and worker, the thinker and poet.

Language, the Socialiser.

Speech has incidentally done man a service so inestimable as to demand a closing word. As we endeavour to recall the successive developments of language, and observe how names once as clearly recognisable as the "meeow" which a child confers upon a cat have become slurred by laziness, or combined with sounds purely interjectional in origin, we catch a glimpse of the highest office borne by speech in the making of man. If a tribe, having arrived at a somewhat full vocabulary, was to continue to enjoy its use, that tribe had to stick together; otherwise words would soon lose their significance. By as much as a language contains terms whose meaning must be learned afresh by every individual, by just so much has that language put a premium upon social ties, upon the capacity and the will to live together, to co-operate in defence or attack. It is only very early in the human day that we can allowably imagine, as at the beginning of this chapter, a wanderer going forth by himself in search of food. In an era far remote in his history man must have found comfort, cheer, and safety in the bonds of what, in the germ, was society. In thus binding men together, in replacing war by peace, in making it gainful as well as right to prefer union to conflict, language has borne a part not second to that of any other faculty of man. He stands the highest of beings not only because of his range of mental power, but because of his sympathy, in so far as he finds his chief happiness in promoting others' weal. Language, which first made human society, is to-day remaking it with closer ties and firmer bonds now that speech is electric and voice answers voice with half a continent between.

CHAPTER XXVI

THE ANCESTRY OF MAN IN THE LIGHT OF NINETEENTH-CENTURY ADVANCES

New Departures.

LANGUAGE, the theme of the preceding chapter, may well continue to occupy our attention. Let us listen for a moment to the click of a telegraph instrument, that we may hear another message than that committed to its wire. A New York merchant, his words reduced to mere dots, dashes, and spaces, is sending an order to his partner in Hong Kong. Within the hour he may receive intelligence borne to Sandy Hook from a steamer whose Marconi apparatus asks only ether as the carrier of its pulses. Next he may converse with a correspondent in the metropolis of Louisiana, every tone and cadence of his voice clearly transmitted for well-nigh nineteen hundred miles. This impressing electricity for verbal communication is a radical departure from all previous methods. It is not as if light of redoubled intensity, a mirror of sharper focus, or a rocket of bolder flight had given a new breadth to old plans of signalling. The feats of electric telegraphy and telephony stand in a category by themselves, distinctly separated from that in which light was the ministrant, and this new category is one of vastly wider scope than the old. What is true of electricity as a conveyer of words is equally true of electricity as a new force within the grasp of man for manifold other services.

A photograph has much the same significance as the telegram which a little while ago we overheard as it sped from New York to Hong Kong. An amateur hands us what on the surface is a picture of Brooklyn Bridge, beneath the surface much more appears. Six minutes ago he snapped his kodak at the great structure, and in the brief interval he has developed his negative, printed and fixed a clear and beautiful positive. To outline the bridge with a pencil in this minute and accurate fashion is utterly beyond our amateur's powers, and might severely tax the skill of a highly accomplished draughtsman. At first the camera, as devised in Italy, was employed that the pencil or the brush might seize the lines and hues of its images. Pencil and brush were cast aside when means were found of making light imprint with accuracy and permanence every detail of a camera's image. In photography, as in telegraphy, progress has lain not in improving an old method, but in supplanting it by a process absolutely different, and in many directions of incomparably broader range.

In the preceding pages there has been a brief recital of the steps by which the mastery of fire led at last to the subjugation of electricity, and depiction for the first time in its course took a new direction by the capture of images in the camera. While the path in each case from the old plane to the new was unmarked by aught in the least resembling a revolution, there was certainly a revolution of consequences most profound when once electricity and the photographic beam had become the docile servants of man. These facts are typical: progress has leaps, as radically new powers fall under human control, and history divides itself into chapters, each distinguished from its predecessors by the arrival of man at a new resource of prime dignity. And these resources do not enter the field of effort as additions merely, but with all the effect of multipliers, as, in the cases of fire, electricity, and the photographic ray, we have remarked somewhat in detail.

The Latest Steps Explain the First.

As we traced the work of the forerunners who smoothed the path for the electrician, long before electricity as a distinct force was recognised at all, we saw that, however long and circuitous the road which stretches from old powers to new, the act of touching the goal-post is sudden enough. All that is needed is the exceptional intelligence of a Franklin, a Volta, a Henry. And thus the latest achievements of man light up those of the earliest days in which he deserved to be called human. Two years ago there was discovered on Southampton Island, in Hudson's Bay, a small tribe of Eskimos so primitive in culture as to be destitute of metals. These men doubtless could speak to each other no more readily, no farther apart, than did their great-grandfathers at the close of the eighteenth century. The leap in verbal communication which has taken place in the past sixty years makes it easy to comprehend how the first leap in language occurred on one memorable day long ago. It was not more difficult for a progenitor of these Eskimos to mean "bear" by a bearish growl than for Professor Bell to convert the word "bear" into electric waves from which the sound may be recovered after a journey half-way across the United States. And the instant that in ancient times a sign or a sound could symbolise and recall anything beyond sight or hearing, a new era dawned for the human soul. The distinction that lifts man incomparably above the creatures next to him is not a matter of muscle, nerve, or skull capacity so much as the intelligence vitally dependent upon those powers of expression and of record which, to repeat a thought of Pascal, make mankind as one man, ever living and always learning. Throughout the pages of this book there has been constant reference to the principle of permutation, formally set forth on page 3. As our argument draws to a close it may be fairly said that there is much to support the view that the supreme acquisitions of man, as they have one by one fallen into his hands, have the distinctness one from another of the successive factors in a permutative series, and enter the field of human progress with a similar multiplying effect.

Accelerations.

Our figures on page 3 indicate something further. We have seen that each distinctively human resource has given rise to still others, which spring from it as flower from seed; and we have observed how powers old and new combine to yield fruits unimaginable before their union. Professor Röntgen's discovery of the X ray was the outcome of uniting the utmost expedients of both electricity and photography. In a parallel indebtedness a telegraphic pulse too feeble to actuate a pencil or a pen, however nice of poise, may register itself upon a sensitive film. The architecture of science has something in common with the rearing of an arch. Hour by hour the voussoirs rise from the ground; at last comes the supreme moment when the keystone is dropped into place, and now that each half of the structure finds its complement in the other, both display a strength wholly new.

When once a trench was dug between the stock now human and its next of kin, either by superior prehension, quicker sight, or a voice readier of modulation, that trench soon grew to a gulf by swift increase of the particular faculty most effective in lifting man above the simple animal. And not only was the capital of human intelligence thus increased, but so likewise was the rate of interest at which that capital was gainful. With the growth of intelligence due to the mastery of fire, its kindler came at length to the creation of that subtiler fire, electricity, rich with gifts, a few of which have been noticed in these pages. The nineteenth century in its seizure of new resources of prime dignity, in its ingenious development of the vital relations between each and every other, has expanded the realm of science more than all preceding time. The rapid augmentation of effect as one multiplier succeeds another in the permutative series on page 3 would seem to outline the growth of human mastership with distinct verity. Not only is the pace of evolution at decisive epochs quickened to a leap, but these leaps may take place at intervals ever shorter as intelligence grows keener, more alive to its opportunities; while the effects of these leaps, as new resources interact one with another, has the result of constantly accelerating the upward march of man. And hence the total period occupied in human evolution may have been much shorter than is commonly supposed.

Gaps in the Genealogical Tree.

The accelerations of human progress afford us an explanation of the gaps which divide man from anthropoid—gaps which have caused many students of evolution to hesitate in accepting the Darwinian theory of human descent.[1] Let us for a moment observe the latest strides of mankind, and they may inform us as to the characteristics of his earliest upward steps. We have seen in our brief survey of certain fields of science that discoverers and inventors are busy, not at a mine of great but definite riches, but rather at the extension of a sphere which touches an ever larger surface of the unknown and explorable, the unattempted and feasible. All this is illuminated by the permutative principle to which, as a guiding thought, we

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[1] Within recent years there has been much discussion by evolutionists of the inheritance of acquired characters. It would seem that evidence in point is adducible in the lengthened fingers and shortened toes of modern man; they clearly indicate that the effects of use and disuse are cumulative as one generation succeeds another.

have constantly referred. If we turn to page 3 once more, we shall remark that 5 factors yield 120 permutations, 96 more than the product (24) of 4 factors; while the product (24) of 4 factors exceeds that of 3 factors (6) by only 18. The difference between one product and the next increases enormously as a new factor enters — with its broadened play of interlacement. The progress of mankind as successively indebted to the upright attitude, the mastery of fire, articulate speech, writing, and the conquest of electricity, cannot be represented by so simple a piece of arithmetic as this, yet it may be justly said that there is an indication of truth in its rapidly expanding divergence of effect as a new factor comes into the account. We have already noted with somewhat of particularity that fire itself has not broadened the horizon of the worker, the explorer, and the thinker as much as the capture of electricity; and electricity has come into harness too recently for its capabilities to be as yet fully discerned.

One of the suggestions which led Darwin to the discovery of the law of natural selection arose from the rule formulated by Malthus — that organic beings tend to multiply in geometrical progression. That rule, however much masked and modified in the complexity of actual life, nevertheless remains potent enough to explain the unrelenting struggle for existence which Darwin has so graphically pictured in every field of natural history. It is in that struggle that favourable variations find their opportunity to survive and to propagate, with the issue of types of life better adapted to surroundings ever changing, to surroundings ever growing in the main more diversified. Of similar elucidating value are the figures in a permutative chain as they succeed each other, and they supplement the suggestion of Malthus in a telling way. When through the brain of a primitive Edison the idea flashes that fire, which he has unwittingly kindled, may be intentionally kindled again by the clash of flint, or the friction of sticks, his exceptional wit means an instant and tremendous impulse forward, first for himself, next for his tribe and his race. And this act of genius has a decisive result in competitions which mean either life or death.

Let us imagine two modern navies equal in every respect except that one has the electric telegraph and that the other has not. Which, in battle, will win? Just as conclusive must have been the verdict when arms of bronze were opposed to weapons of stone, or other equal advantage came into the hands of one particular tribe or race, while their rivals missed the new factor of supremacy by however little. The warfare which in modern times has extirpated so many native races in America, Africa, and Australia, may have had its counterpart in the battles which may once have enabled the ancestors of these very savages to be victors in contests where they alone remained alive. Thus, for the third time, the principle of permutation casts an illuminating ray upon the descent of man, by suggesting how it may have come about that here and there links are missing to connect him with his kindred, to make the adducible proofs of evolution as convincing with regard to man as they are with regard to other species, and to nature herself as a whole.

To sum up in a final word the conclusions at which we have arrived: (1) The pace of progress is quickened to a leap as a distinctly new resource flowers from faculties long enjoyed. (2) Such a resource, when of prime dignity, enters the field of human capability with multiplying effect. (3) This results in an increasing width of gap between the highest and lowest human races as evolution takes its course; and effects a severance, all but infinite, betwixt man and the primates who now stand next beneath him in the tree of life.

APPENDIX

THE GOLDEN AGE OF SCIENCE

The Supremacy of Science.

THE nineteenth century offers us one contrast with its predecessors more conspicuous and significant than any other. While its feats of science far outdistance those of any preceding era, and, indeed, in many directions exceed the sum total of previous human accomplishment, its additions to great literature, to the masterpieces of fine art, are not striking, either in quality or compass. The artist and the man of letters are perforce disposed to marvel at the remoteness of the day when sculpture, architecture, and poetry reached their culmination in Greece and Palestine. To come to supremacies less remote—Dante and Shakespeare, Titian, Raphael, and Valasquez remain unapproached. But in the realm of science, of ordered knowledge, we face to-day the east and not the west, and here the horizon ever retreats as the explorer advances, ever widens the higher he climbs. The distinction, worthy of all emphasis, has been drawn by Sir William Roberts:

> The evolution of science differs fundamentally from that of literature and the fine arts. Science advances by a succession of discoveries. Each discovery constitutes a permanent addition to natural knowledge, and furnishes a point of vantage for, and a suggestion to, further discoveries. This mode of advance has no assignable limits; for the phenomena of nature—the materials upon which science works—are practically infinite in extent and complexity. Moreover, science creates while it investigates; it creates new chemical compounds, new combinations of forces, new conditions of substances, and strange, new environments—such as do not exist at all on the earth's surface in primitive nature. These "new natures," as Bacon would have called them, open out endless vistas of lines of future research. The prospects of the scientific inquirer are therefore bounded by no horizon; and no man can tell, nor even in the least conjecture, what ultimate issues he may reach. . . .

The difference here indicated between the growth of art and literature is, of course, inherent in the subjects, and is not difficult to explain. The creation of an artist, whether in art or literature, is the expression and the embodiment of the artist's own mind, and remains always, in some mystic fashion, part and parcel of his personality. But a scientific discovery stands detached, and has only an historical relation to the investigator. The work of an artist is mainly subjective; the work of a scientific inquirer is mainly objective. When and after a branch of art has reached its period of maturity, the pupil of a master in that art cannot start where his master ended, and make advances upon his work; he is fortunate if at the end of his career he can reach his master's level. But the pupil of a scientific discoverer starts where his master left off, and, even though of inferior capacity, can build upon his foundations and pass beyond him. It would seem as if no real advance in art and literature were possible except on the assumption that there shall occur an enlargement of the artistic and literary faculty of the human mind. No such assumption is required to explain and render possible the continuous advance of science. The discoverer of to-day need not be more highly endowed than the discoverer of a hundred years ago; but he is able to reach farther and higher because he stands on a more advanced and elevated platform built up by his predecessors.[1]

The Scientific Method.

Above and beyond any particular gift of science,—a new chemical element, a ray of new penetration, or even a new rule of physical and chemical action,—there has been evolved something more and greater: nothing else than perfecting the instrument by which discovery carves its path and particular rules are merged into universal law—the scientific method, now confessed the one trustworthy means for the winning of all truth. Beginning in the comparatively simple sphere of natural science, it has passed to the more difficult fields of art, history, and criticism, to reforms social and political, moral and religious. In all its work, whether it has to do with the mere machinery of the livelihoods, or with the things of the mind and heart, the conscience and the will, it means reality, accuracy, fidelity to the directly observed and carefully comprehended fact. It disregards traditions, legends, and guesses, however closely associated with great names or hoary institutions. In their stead it is erecting a new authority, which finds its sanctions in knowledge, in observation, experiment, reasoning, in untiring, impartial verification. When it gives play to the imagination and offers a conjecture in the hope that it may be helpful, the conjecture is plainly labelled as such, and is with-

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[1] Harveian oration, delivered before the Royal College of Physicians, London, October 18, 1897. *Nature*, October 28, 1897.

drawn the moment that a sound objection so demands. The man of science ever rejoices when he finds, as he often can, that men of old had a forefeeling of modern scientific truth; but under all circumstances he fully declares exactly what he discovers, however much his disclosures may cause a valued heritage to be disprized. Triumphs to us inconceivable doubtless await the centuries to come, but there will remain as the inalienable glory of the nineteenth that to the old question, What is truth? it first gave, not the old answer, Whatever has been so considered, but Whatsoever can be proved.

INDEX