LITTLE BLUE BOOK NO. 994
Edited by E. Haldeman-Julius

Physics Self Taught

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INTRODUCTION

Until recent times the study of *Physics* included virtually all the natural sciences, and was therefore synonymous with "Natural Philosophy". With the rapid advancement of science in many fields, especially during the nineteenth century, and the consequent need for specialization on the part of investigators, Chemistry, Astronomy, Biology, and Geology became separate departments of science.

To the domain of Physics was left only such closely related subjects as *mechanics*, *heat*, *electricity*, *light* and *sound*—all of which are phenomena of inanimate matter involving no changes in chemical composition.

More recently, owing to still further advances, there has been a marked tendency toward a reunification of the natural sciences, and we speak now of electro-chemistry, physical chemistry, biophysics, biochemistry, and so on. Nevertheless, it is still expedient to limit the study of physics proper to problems of mechanics, heat, light, sound and electricity.

In view of what has just been said, it is perhaps hardly necessary to point out that the phenomena just enumerated lie at the foundation of all other sciences—are the basic phenomena of the cosmos; hence the study of most natural processes presupposes on the part of the student at least an elementary knowledge of physics.

Since the subject of electricity, and the problem of the structure of atoms, etc., have already been treated in other Little Blue Books,[1] the subject-matter of the present volume will be limited to the principles of dynamics, heat, light and sound, with but a brief reference to electricity. These topics cannot, of course, be discussed in all their aspects. Some important physical topics will have to be omitted. It is hoped, however, that the information given will be neither less sound in principle nor less interesting to the reader because of the space limitations imposed.

It is hoped also that the thoughtful reader, having learned the principles discussed herein, will not find it difficult to employ them in the solution of many everyday problems of a practical nature. The reader who wishes to go farther into the subject would do well to take up next some such illustrated work as Prof. H. E. Hadley's "Everyday Physics" (1924), or "Practical Physics", by N. Henry Black and Harvey N. Davis (1920), to be followed by, say, "Elements of Physics", by F. W. Merchant and C. A. Chant (1924), the last named being a more advanced treatise, but nevertheless still falling within the definition of "elementary". See also the Physics list in "A Map of the World of Knowledge", by Sidney Morse, Introduction and Booklists by Jesse Lee Bennett (1925).

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[1] See, particularly, Moritzen, "Electric Energy: What It Does and Promises" (No. 510); Shipley, "The Principles of Electricity" (No. 133); also by Shipley, "A B C of the Electron Theory of Matter" (No. 603); "Electricity and Life" (No. 722); "Origin and Development of the Atomic Theory" (No. 608); "Man's Debt to the Sun" (No. 808).

PHYSICS SELF TAUGHT

CHAPTER I

GRAVITATION, INERTIA, FORCE, MOTION

One of the problems of nature which greatly perplexed men of science from the days of the early Greek physicists, and down into quite modern times, was the movement of the heavenly bodies and the falling of all free bodies near the earth to a place at rest on its surface.

Until the time of Galileo (1564-1642), it was generally believed that the "heavier" the substance, the faster would be its descent toward the earth; in other words, that the speed of a falling body depended upon its weight. This notion was forever dispelled by Galileo's famous experiment of dropping heavier and lighter balls, of different substances, from the "leaning tower of Pisa".

It was then demonstrated that, other things being equal, all bodies fall with the same velocity in a given time; *time*, not *weight*, being the determining factor of the body's speed, at any given moment, in falling from a height to the surface of the earth—more precisely, toward the center of the earth.

The metal at the end of a builder's plumb-line always "points" to the center of gravity—is "attracted" by a "force" which we call "gravity". This "force of gravity" always acts in the direction of the line joining the center of the falling body to the earth's center, and therefore it is always perpendicular to the earth's surface. The force of gravity acting on *any* body is called the *weight* of the body.

If a spiral spring is substituted for the cord of the plumb-line, we have an instrument called a *spring-balance*, by which we can measure the force of gravity on any body; i. e., the weight of the body.

Since nearly everyone has used a spring-balance at one time or another, I need not go into detail on this phase of the subject. But not many persons have carried a spring-balance to the top of a high mountain for the purpose of weighing the same object there that has been weighed at the earth's surface. If one should do so, however, he would find the object weighing less and less with every increase in altitude, though the quantity of the material in the object remained unaltered. Why? For the simple reason that the weight of any given object depends to some extent upon the distance between the center of the body and the center of the earth.

An object which weighs one pound at the earth's surface (which is about 4000 miles distant from the earth's center) would weigh but four ounces if it could be transported to an altitude of 4000 miles, since doubling the distance from the earth's center reduces the force of gravity by one quarter of its former magnitude—the attraction between two bodies being directly proportional to the product of their masses, and inversely to the square of the distance between them. This statement is known as Newton's Law of Universal Gravitation.

In the case of a one-pound mass placed 2000 miles from the earth's surface, or 6000 miles from its center, the weight would be reduced to 4/9 of a pound, since this distance apart is 6000/4000, or 3/2 of the former distance, and the force of attraction $= \frac{1}{(3/2)^2} = 4/9$ of 1 pound-force.

In a mass weighing one pound—a pound-mass—the attraction of the earth on it is a *pound-force.* (The mass also attracts the earth with an equal force, since "action and reaction are equal". But we shall come to this point again later on.)

What we call the *weight* of an object, then, is a variable quantity, depending upon the distance of the body from the center of the earth—a homogeneous sphere always attracting a body outside of it as if all its matter were collected at its center. But since the *quantity of material* in the object always remains the same, we can, for all practical purposes, speak of the *mass* of a given body as a *constant quantity,* whatever and wherever it may be. Hence it is apparent that *mass* and *weight* are not equivalent terms.

Even on the earth's surface the weight of an object somewhat varies. The earth is not a perfect sphere, being slightly flattened at the poles, at which location the object to be weighed would be nearer the earth's center, and therefore heavier—i. e., the attraction of the earth on the mass would be greater—to the extent of about 0.5% (1/568), as compared with a point anywhere on the bulging equator. Part of this difference in weight at the equator, however, would be due to the fact that an object at the equatorial zone of the earth would be revolving at a greater velocity than at points nearer the poles, so that at 1000 miles an hour —the equatorial velocity of the earth's rotation on its axis—the *centrifugal* force would counteract to some extent the *centripetal* attraction; the object thereby having a tendency to be thrown off the earth, just as mud is thrown tangentially from a rapidly revolving wheel.

ANCIENT "PROOF" OF EARTH'S FLATNESS

The Fundamentalists of by-gone days used to argue that the Bible conception of a flat earth must be correct, that the earth could not be a sphere (as had been argued by certain pagan philosophers) but must be flat: first, because four angels were recorded as having stood on the "four corners" of the earth; secondly, because people could not live on the "other side" of the earth (the Antipodes), for in this case their feet would be higher than their heads, and they would have to hang on by their feet like flies to a ceiling, which anyone could see was "absurd" as well as "contrary to Holy Scripture". But even Fundamentalists now—outside of the Dowieites and Koreshites—admit that the earth is virtually a sphere. We know now that the earth attracts to its center all objects on its surface, and that what was "down" twelve hours ago is "up" now, and *vice versa*; that in nature there is really no "up" and no "down", excepting as relative to the earth's center, towards which our feet are always directed.

REST AND MOTION

Before going more into detail about the laws of motion, let us place ourselves in imagination back in the sixteenth century, and face the problem of the movement of bodies in the same way it was confronted by our forefathers; and then trace the gradual growth of the science of dynamics down to our own times.[2]

Everyone had noticed, of course, that any object released from the hand would immediately fall to the ground; and that any object projected into space above us would soon come to a momentary standstill and then fall to earth again. This seemed perfectly natural, since the objects concerned possessed the property of weight, and they would "fall" through the tenuous atmosphere for the same reason that stone or iron would "sink" in water. The conception of a "force" in the earth which "pulled" them did not at first occur to philosophers.

They were puzzled, however, to explain why the planets kept revolving around the earth (as they thought) without any force to keep them in motion and to prevent them from falling down to the earth. Why should the moon,

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[2] See also, in this connection, Shipley, "Greek Physics and Modern Science," Little Blue Book No. 837.

for example, follow its regular pathway around the earth?

It was all but universally believed, down to the time of Copernicus (1473-1543), and later—on Scriptural grounds—that the sun, planets, and stars all revolved around a stationary earth, our planet being regarded as stationed at the center of the universe.

The question naturally arose, what held the celestial bodies in their proper orbits, and what pushed or pulled them along in their paths? For it was taken for granted that the *natural* state of a body was one of *rest.* If anything moved, it was because something or somebody pushed or pulled it from its "natural" position of rest. To our philosophic forebears, learned in the angelology of the "Word of God", the answer was readily forthcoming: the planets and stars were under the personal direction of angels, or genii, pulling or pushing the heavenly bodies along in their apparent courses, holding them ever on the proper track, so to speak.

The great French philosopher, Réné Descartes (1596-1650) rejected the popular theory concerning the angelic impulsion of the planets, and assumed for the purposes of his all-embracing mechanical system of the world that an original impulse was given the mass of matter composing the cosmos by Deity. Given the continuance of this motion, with God as mover, all subsequent cosmic events could be accounted for, he contended, on strictly mechanical principles. *Motion* (locomotion) was, for Descartes, the true physical conception, the basic principle of all natural philosophy. It is to this great geometer and philosopher that we owe two fundamental laws of nature, or of motion.

Descartes' first law states, in effect, that, extraneous causes not intervening, every particle of matter in the universe always continues in the same state of motion or of rest; and his second law affirms that simple or elementary motion is always in a straight line (*Principia*, pt. ii, 37). This is what the modern physicist means by *inertia*.

DESCARTES: THE PRINCIPLE OF INERTIA

Descartes' Law of Inertia was subsequently stated very simply by Sir Isaac Newton (1642-1727), as follows:

Every body continues in its state of rest, or of uniform motion in a straight line, unless it be compelled by external force to change that state.

This statement is now generally known as Newton's First Law of Motion, published in 1687 in his famous *Principia* (in full, *Principia Mathematica Naturalis Philosophiae;* i.e., "The Mathematical Principles of Natural Philosophy").

Everyone knows that a ball, for example, lying at rest on the ground, will remain at rest forever unless some force operating on it sets it in motion. But not everyone knows that if once set rolling it would continue to roll on forever unless some force stopped it. The belief was (and still is among some persons) that a body moves only so long as a force of some kind operates upon it, impelling it along. Hence the idea that the planets and the moon were carried around in their orbits by angels.

THE FIRST LAW OF MOTION

The first law of motion asserts the physical truth that a state of uniform motion is just as natural as a state of rest. It is natural for us to regard rest as the natural state, and motion as an enforced one. Nature, however, knows no such distinction, though it is easy to be deceived by appearances into thinking otherwise.

For example, we note that when we throw a ball on a level field it soon comes to a standstill. We immediately assume that the original force exerted upon the ball has ceased operating, and that the ball stopped rolling because there was nothing—no *force* behind it—to keep it going; that it just *naturally* came to rest. This is a mistaken view.

What is required in the case of the ball to keep its motion continuous forever is not more impelling force, but the absence of friction and a cessation of gravitational attraction toward the earth's center of gravity. Had the ball been projected straight upwards with an initial velocity of, say, eight miles a second, it would continue its motion in a straight line throughout all eternity unless it collided with, or came within the gravitational control of, some other body. It would require nothing whatever to "keep it going" forever. This is the meaning of "the first law of motion". If a body is at rest, we don't need to ascertain what it is that *prevents its moving.* But if it is already in motion, and then comes to a standstill, the question arises, "What stopped the rolling ball?"

Obviously, its course was impeded by friction with the earth's surface, and by repeatedly rising against the attraction of gravity in passing over pebbles, grass, etc. It had also to resist the pressure of the atmosphere, which has a noticeable effect even on the passage of a projectile from a high-power gun. The force of gravity, acting vertically, tends to pull the flying ball or projectile downward, becoming more powerful as the speed is diminished by atmospheric resistance.

Everyone has observed how an ordinary wagon-wheel soon comes to rest after being set rotating. A well adjusted bicycle-wheel, on the contrary, once set in motion, continues to revolve for quite a long time; the "external force"—the friction at the axle—is in this case much smaller than in the case of an ordinary vehicle.

That a body which is moving tends to continue moving in the same direction is a principle utilized by every schoolboy who wishes to jump a ditch or leap over an obstruction. He takes a run, leaps into the air, and his body, persisting in its motion, carries him across the ditch or over the obstacle. Contrary-wise, if we are standing still in a street-car which has come to a sudden stop, we tend to lurch forward; and when it starts again we tend to fall in the opposite direction.

A SIMPLE EXPERIMENT

The principle of inertia is well illustrated by an experiment familiar to all students of physics. If we lay a visiting-card (for example) on the top of a wine-glass, and then place a penny on the card, and flick the edge of the cardboard as quickly (or violently) as possible, aiming the blow quite horizontally, the cardboard will be flung to a distance, but the coin will drop to the bottom of the glass. Or the same result may be attained by snapping the card out. Bodies act as if disinclined to change their state, whether of rest or motion.

Because of this tendency, a heavy flywheel is used with stationary steam and gas engines, since every particle in the wheel tends to continue moving at the same speed, thus tending to insure that the speed of the engine does not vary during each stroke of the piston. "The earth itself is like an enormous flywheel, always rotating at a constant speed; its inertia insures that the speed remains constant."[3]

THE EARTH A GYROSTAT

The earth may be compared to a *gyrostat*, with the axis around which it rotates pointing towards the pole-star.

The gyrostat, to borrow Hadley's excellent brief description (p. 31), "consists of a heavy metal wheel mounted on *gymbals* (i. e., two concentric rings with their axes at right

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[3] See Hadley, "Everyday Physics", 1924; pp. 30-31.

angles). This allows the wheel to rotate in any plane. Any movement given to the base of the instrument, when the wheel is spinning rapidly, will not affect the direction in which the axis of the wheel is pointing. If, when started, it was pointing towards the pole-star, it will continue to do so. This is the principle of the modern *gyro-compass*, now used on ships instead of the magnetic compass; if set so as to point towards the true north, it continues to do so whatever may be the movements or position of the ship, providing of course that the speed of rotation is maintained."

As is well known, it requires a much greater force to impart a great velocity to a body than to give it a small one, while to stop a rapidly moving body is much harder than to stop one moving slowly. In experiencing the impact of a person with whom we collide in suddenly turning a corner, or otherwise, we realize that the weight of the persons colliding and the speed with which both are walking or running has much to do with the seriousness of the result. We are concerned here with two factors, namely, mass and velocity, and in physics the two are combined in the phrase "quantity of motion," or *momentum*.

Mathematically expressed, momentum is proportional to both the mass and the velocity of a body; thus

$$\text{Momentum} = \text{mass} \times \text{velocity} = mv,$$

where m is the mass of the body and v its velocity of translation. If either the mass or the velocity is doubled, the effect in a collision is doubled; if both are doubled, the effect is quadrupled.

INDEPENDENCE OF FORCES: THE SECOND LAW OF MOTION

The Second Law of Motion, as formulated by Newton, states that change of motion (momentum) in a given time, is proportional to force applied (impressed) and takes place in the direction (of the straight line) in which the force acts.

The simplest and best illustration of this second law of motion is to be found in Todd's "New Astronomy" (pp. 373-374), and is as follows:

> From the smooth and level top of a table or shelf, brush a coin or other small object off swiftly with one hand; it will fall freely to the floor a few feet away. Repeat until you find the strength of impulse necessary to send it a distance of about two feet, then four, then six feet. With the other hand, practice dropping a coin from the level of the table, so that it will not turn in falling, but will remain nearly horizontal till it strikes the floor. Now try these experiments with both hands together, and at the same time. Repeat until one coin is released from the fingers at the exact instant the other is brushed off the table. Then you will find that both reach the floor at precisely the same time; and this will be true, whether the first coin is projected to a distance of two feet, four feet, six feet, or whatever the distance. Had gravity not been acting, the first coin would have traveled *horizontally*, on a level with the desk, and would have reached a distance of two feet, or four feet, proportioned to the impulse. What the second law of motion asserts is this: that the constant force (gravity in this case) pulls the first coin just as far from the place it would have reached, had gravity not been acting,

as the same force, acting vertically and alone, would in an equal time draw it from the state of rest. Whatever distance the coin is projected, the "change of motion" is always the vertical distance between the level of table and floor, that is, "in the direction of the straight line in which the force acts." The law holds good just the same, if the coin is not projected horizontally, provided the floor (or whatever the coin falls on) is parallel to the surface from which it is projected.

These results follow in accordance with the laws of motion discovered by Galileo, his second law recognizing "the independence of different motions"; and upon his first two laws depends the true theory of projectiles.

Each force, as we have just seen, produces its own effect, measured by change of *momentum*, quite independently of any others which may be acting on the body. A horizontal velocity can have no effect on a vertical one, either to increase or to diminish it.

GALILEO: ACCELERATED MOTION

Before the time of Galileo, it was the custom of natural philosophers to attempt the solution of physical problems either by purely speculative methods or by mathematical calculation. Galileo introduced the method followed since by all great discoverers, namely, the combination of experiment with calculation. It was through his transformation of the concrete—through experimentation—into the abstract, by calculation and the careful comparison of results, that Galileo discovered the *laws of falling bodies.* He showed that bodies falling freely toward the earth do not fall at a uniform velocity, but that the speed increases with "a uniformly accelerated motion"; that is to say, they travel at a definite increase of speed with each second elapsing after release of the object. Galileo "proved that the velocities acquired are in the direct, and the spaces traversed in the duplicate ratios of the times, counting from the beginning of motion." (I shall make this principle clearer as I go on.)

GALILEO'S INCLINED PLANE

Galileo, of course, had no means of determining accurately the time it takes for a body to fall various distances. A freely falling body acquires velocity so rapidly that the Italian savant was obliged to devise some means of "diluting" the force of gravity and of increasing the time of fall so that it could be measured with at least a fair degree of accuracy. To this end he cut a trough one inch wide in a board twelve yards long, and rolled a brass ball down the trough, which formed an inclined plane:

> After about 100 trials made for different inclinations and distances, he concluded that the distance of descent for a given inclination varied very nearly as the square of the time. It is remarkable that he was so successful in this experiment when we consider how he measured the time. He attached a very small spout to the bottom of a water pail and caught in a cup the water that escaped during the time the ball rolled down a given distance. Then the water was weighed and the times of descent were taken as proportional to the ascertained weight.[4]

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[4] Black and Davis, "Practical Physics", 1920, pp. 140-141.

In short, by these ingenious methods, crude as they were, Galileo proved that the distance traveled by the ball varied approximately as the squares of the time.

This gradual change of speed (or velocity) is termed by the physicist *acceleration*—the acceleration due to gravity; and Galileo proved that *all* freely falling bodies have the same acceleration. The value of the acceleration of gravity is a *constant*, and is now known to be about 980 centimeters-per-second a second, or about 32.2 feet per second in each second. It varies a little from place to place. Acceleration is defined as rate of change of speed (or velocity). When the velocity is increased, the acceleration is *positive*; when it is decreased, the acceleration is *negative*. The latter is sometimes called a *retardation*.

LAWS OF ACCELERATION

In general,

Acceleration = gain in speed per unit time, and acceleration is always to be expressed as so many speed units per time unit.

LAW I. If the acceleration is constant, the speed acquired is directly proportional to the time.

Final velocity = acceleration × time

$$v = at$$

LAW II. If the acceleration is constant, the distance traversed from rest varies as the square of the time.

LAW III. If the acceleration is constant, the speed varies as the square root of the distance traversed.

If we know the *average* speed of a body during any period of time, and the duration of the period, the product of these will give the total distance traversed in that interval of time. In the case of a falling stone, starting from rest, at the end of the *first* second its velocity is 32 feet per second; and its average velocity *during* the first second is $(0 + 32)/2$ or 16 feet per second. At the end of the second second the velocity is 64 feet per second; and its average velocity during the first two seconds is $(0 + 64) \div 2$ or 32 feet per second. Similarly, its average velocity during the first three seconds is 48 feet per second.

Since
space traversed = average velocity × time,
then space traversed in first second
is (16x1) feet

and space traversed in first 2 seconds is $\left\{\frac{0+64}{2}\right\} x\ 2 = (16x2^2)$ feet

and space traversed in first 3 seconds is $\left\{\frac{0+96}{2}\right\} x\ 3 = (16x3^2)$ feet

These results clearly show that the space traversed is proportional to the square of the time occupied.[5]

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[5] Cf. Hadley, Chapter III.

THE THIRD LAW OF MOTION

Galileo's theory of the inclined plane, combined with his satisfactory definition of "momentum," led him towards the third law of motion, given in his treatise, "*Della scienza meccanica.*" Owing to the fact that Newton formulated the three laws of motion in more precise and succinct terms, his name is always attached to them; hence, we speak of Newton's laws of motion. As expressed by Newton, the third law is as follows: *To every action there is always an equal and contrary (opposite) reaction; or the mutual actions of any two bodies are always equal and oppositely directed.*

Says Newton: "If you press a stone with your finger, the finger is also pressed by the stone. And if a horse draws a stone tied to a rope, the horse (if I may so say) will be equally drawn back toward the stone; for the stretched rope, in one and the same endeavor to relax or unstretch itself, draws the horse as much toward the stone as it draws the stone toward the horse." In short, action and reaction are always equal. "To have a single force is impossible. There must be, and always is, a pair of forces equal and opposite."

Whenever there is a force in nature, there must be not only two bodies involved, but *another force.* Forces never act singly, but always in pairs. A train will pull back on a locomotive just as hard as the locomotive pulls forward on the train. When a bullet is fired from a rifle, the explosion pushes the rifle backwards with just as much force as it pushes the bullet forward. The rocket is shot skyward by a stream of gases given off at high velocity from the burning gunpowder. "The same push discharging the gases acts in the opposite direction on the cartridge of the rocket, and this is propelled upwards." The forces acting in opposite directions are equal.

Action and reaction are always equal and opposite. When any heavy object is pulled downward by the earth, the heavy object must be pulling the earth upward with an equal force.

But force is sometimes applied to a body which is "still," and no movement of the body results, as in the case of a man pushing against a stone wall, or a large boulder, or what not. And just so, if a body suspended in the air does not fall toward the earth, it is because it is kept from falling on to the earth by some opposing force. If a pound weight is held in the hand, it is opposed by muscular force. If it rests on a table, gravity is opposed by cohesion, which holds the fibers of wood together. The force of gravity acts vertically downward, and any force which opposes it must act vertically upward, as a heavy weight suspended at the end of a rope or chain. Gravity is offset by the cohesion or tenacity of the molecules of the rope or the chain.

The effect of two or more forces acting at the same point is called the *resultant*. For example, if a body weighing 30 pounds is pulled upward by a force of 50 pounds, the effect will be a motion upward as if a force of 20 pounds were acting alone.

No one knows for a certainty just what the force we call *gravity* is. But we call that force which causes an unsupported body to fall toward the earth "gravity."[6]

UNIVERSAL LAW OF GRAVITATION

The force of gravity acting between two bodies, whether on or near the earth or at a vast distance, is always dependent upon the product of the masses of the two bodies, and is inversely to the square of the distance between them. If the distance separating two bodies in space be multiplied by two, the intensity of gravity between them would be but one-fourth as great, and so on.

The gravitation of the earth and moon—or that between any other two bodies—is really the mutual attraction of all the discrete particles composing both these bodies. Thus the universal law of gravitation may be stated as follows: *Every particle of matter in the universe attracts every other particle with a force exactly proportional to the product of the masses, and inversely as the square of the distance between them.*

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[6] On the Einstein theory, gravitational force is not a real force, but merely a manifestation of *inertia*, and inertial mass is identical with gravitational mass. But this subject is too highly technical for popular discussion. Suffice it to say, that it is not necessary to conceive of gravitation as a *pulling* of an object toward the earth. See Hudgings, "Introduction to Einstein", Little Blue Book No. 408; also Floyd Darrow, "Masters of Science and Invention".

EARTH AND MOON SYSTEM

It is sometimes asked, "If the earth is pulling the moon and the moon the earth, why does not the earth, having so much greater mass than the moon, pull it down upon us?"

As a matter of fact, if the moon were to come to a gradual standstill in its orbit—a sudden stoppage would result in its destruction—the mutual attraction of the two bodies would undoubtedly draw them together in a mutual collision. But the moon has never been stationary in relation to the earth, and its direction of motion has always been tangentially *away* from the earth. Were it not for the attraction of the earth's gravitational field, the moon would continue its course in a straight line, away from the earth (ignoring for the moment the effect of the sun's "pull"). But the earth's gravitational attraction compels the moon continually to "bend" in its course, thus holding our satellite in its orbit, forcing it to "fall" around the earth, instead of flying off at a tangent.

Now, the force of gravity can be measured by the change of position which it produces, and, in the case of the moon, this body should be attracted in the direction of the earth, despite its orbital velocity of 0.640 of a mile per second.

Newton knew that at the surface of the earth, about 4,000 miles from the center of attraction, bodies fall (about) 16 feet in the first second of time. He also knew that the moon is distant from the earth (on an average) about 240,000 miles, or 60 times more distant than an object on the surface of the earth is from the center of gravity. Knowing also that the force of gravity diminishes exactly as the square of the distance increases, it was apparent that the moon's course should be diverted from a straight line—

$$\frac{1}{(60 \times 60)} \text{ of } 16.1 \text{ feet;}$$

or, 1/20 of an inch in each second. And this proved to be the case. Since the circumference of the orbit of the moon (considered as a circle) is 1,509,000 miles, traversed in 27 d. 7 h. 43 m. 11.5 s., it must travel at the average velocity of 0.640 miles, and in going 6/10 of a mile a second it deviates from a straight line by only 1/20 of an inch. Thus there is no danger that the force of the earth's attraction will ever draw our friendly satellite down upon our heads.

The foregoing principles also explain, of course, why our earth, in turn, does not fall into the mighty sun. The average velocity of the earth in its annual journey around our central luminary is 18½ miles per second, and in this time it is "pulled" from a straight course only 1/9 of an inch by the sun's attraction. But this apparently slight deviation of the earth's course from a straight line is equivalent to a strain on an ordinary steel rod or cylinder 3,000 miles in diameter! That is, a steel beam of this thickness would be required to hold sun and earth together if the gravitational force that now binds these bodies were annihilated.

It was the sublime task of Newton to prove that the force that holds all free bodies to the earth, including its own atmosphere, and confers the property of "weight" upon all substances, is universal in its action on all bodies, whether upon the earth's surface, or upon the moon, planets, or comets. All alike were proved by this great thinker to be subject to *universal gravitation.* He did not, indeed, discover *what gravitation is;* but he clearly formulated the *laws* in accordance with which it acts or produces its effects, instantaneously, over all distances, however small or however great they may be.

CHAPTER II

THE NATURE AND SOURCE OF HEAT
EXPANSION AND TRANSMISSION

While heat is produced by combustion, friction, and percussion, our most important source of heat, as everyone knows, is the sun. Even the heat produced in burning wood, coal, oil, or gas comes indirectly from the sun. But the physicist, as such, is not concerned with heat as derived from chemical processes in our stoves and furnaces.

So long ago as 1798, Count Rumford (Benjamin Thomson—1753-1814) proved, by means of a bar of steel pushed with great force into a hole in a rapidly rotating bronze cylinder, that heat could be produced by friction, and was therefore not "a subtle weightless fluid called *caloric*." About the middle of the nineteenth century, James Prescott Joule (1818-1889), of Manchester, showed that the quantity of heat produced was proportional to the mechanical work done—"the mechanical equivalent of heat"—twice as much heat requiring twice the amount of work, and so on. In his delightful lectures on "Heat Considered as a Mode of Motion." John Tyndall (1820-1893) did much to bring before the public true conceptions of that form of energy which we call "heat."

TRANSFORMATION OF ENERGY

The savage who employs a fire-drill could not explain *why* heat is developed by his operation, nor could he tell what is happening to the molecules which form the substances of the wood to be ignited. But the student of physics is asked, "What becomes of the energy of the body when its motion is stopped by friction or collision?"

The answer given in our modern text-books is: "It is changed into motion of the molecules of the body, and the more vigorous the motion of the molecules the more heat the body receives. Consider what happens when a body, a piece of lead for instance, is heated. The molecules within it vibrate back and forth, striking their neighbors harder and harder as the temperature rises. This shaking about of the molecules becomes so vigorous that the bonds between them are weakened, the lead softens and then melts. After this the molecules move freely about in the liquid, and as the heat is still further applied they fly off and the liquid evaporates or turns into vapor."[7]

Heat may be *produced* by mechanical action, chemical action, electrical action, or by the sun. But nothing new is thereby *created*. All that happens is that one form of already existing energy is transformed into some other form of energy.

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[7] Merchant and Chant, "Elements of Physics", 1924, p. 205.

TRANSFERENCE OF HEAT

While the question of whether such a medium as the *ether* actually exists is still a matter on which doctors of philosophy do not all agree, it is a very convenient conception, and makes it possible to explain many problems on easily understood principles. Thus the physicist accounts readily for the transmission of energy or the transference of heat, by assuming that a real, but by us imperceptible, substance pervades all space, penetrating molecules and atoms, and that the vibrating molecules of a hot body set up disturbances in this ether, which transmits the disturbances in all directions by a species of wave-motion, much as sound waves spread out in the atmosphere from a vibrating body.

"When these ether waves fall upon matter, they tend to accelerate the motion of its molecules and to heat it." A hot body emits radiation *in all directions and in straight lines*, which is quite different from *convection* and *conduction*. "Transmission by convection always takes place in one direction, namely, by upward currents; and conduction is not restricted by straight lines, for a bent wire conducts as well as a straight one."

CONDUCTION—CONVECTION—RADIATION

Heat is conveyed from a fire by three different methods. For example, if we heat a poker the warmth is conveyed down to the handle, along the metal, from one layer to the next. This is the method of *conduction*. But the warmth of a stove-pipe is due to the heat conveyed by the moving stream of hot gases, flowing upward, by *convection*. The rise of the mercury in a thermometer is transmitted by a process known as *radiation*, consisting of minute, transverse waves in the ether, conveying *energy*. These waves are not absorbed by the air through which they pass, hence the air is not perceptibly warmed. The human body, on the other hand, like most other forms of matter, stops the waves, *absorbs* them, and is thereby warmed by the agitation of the molecules of the cells of the body.

A good conductor of heat feels colder to the hand than a poor conductor. Metal is a good conductor, wood a poor conductor. If we pick up an axe-handle on a cold day it does not *seem* to be so cold as a bar of iron lying by its side. The iron *feels* colder than the wooden object, but in reality both have the same temperature. The sensation of coldness experienced by picking up the iron bar is due to the fact that metal is a good conductor, and quickly removes the heat from the hand holding it. Wood being a bad conductor, the warmth of the hand is not conveyed beyond the part of the surface actually touched; so the sensation of coldness soon ceases. Earthen teapots require no wooden handle for the reason that the material itself is a bad conductor of heat. The eiderdown quilt is both very light and a poor conductor of heat; hence its desirable properties.

WHY HOT WATER BREAKS GLASS VESSELS

Housewives who know by experience that thin glass vessels will stand very hot water better than thick glassware, are usually quite unable to tell just why this is so. The simple explanation is that the part of the glass which suddenly comes into contact with the hot water quickly expands, the expanding part breaking away from the part which is not expanding, the effect of the heat being local, because glass is a bad conductor of heat. The thicker the glass is, the poorer the conductor.

On the same principle, in pouring a hot liquid, say fat, into a glass, a metal fork or similar object should be inserted first, to keep the glass from cracking.

THE THERMOS-FLASK EXPLAINED

The thermos-flask is an unusually bad conductor of heat. "It consists," says Hadley,[8] "of a double-walled glass vessel, the two inside surfaces having been previously silvered, like a mirror. The air between the walls is pumped out as completely as possible, and the space is hermetically sealed. A vacuum will not transmit heat either by conduction or convection, owing to the absence of any material substance. Radiant heat, however, passes readily through a vacuum—just as readily as visible light—but it is reflected back when it falls upon the surface of a mirror. Hence, in the thermos-flask,

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[8] p. 192

the combination of vacuum and silvered surfaces renders the passage of heat to or from the interior of the flask very slow. Hence a hot substance inside a thermos-flask keeps hot, or a cold substance such as liquid air remains cold because heat cannot readily get at it."

EXPANSION BY HEAT—SOLIDS

It may be set down as axiomatic that virtually *all solids expand when warmed and contract when cooled.* Probably every adult has noticed that when a railroad track is laid, a small space is left between the ends of the rails, to allow for expansion of the steel in hot weather. Iron bridges are usually fixed at one end only. Iron rims are more conveniently placed on wheels when they are expanded by heat; upon cooling they contract, and thus automatically "lock" themselves on.

The easiest way to loosen a glass-stopper in a glass bottle is to rotate the neck of the bottle over a small flame until it is nearly too hot to touch, and then tap it with another glass bottle. This is more effective than tapping with any other substance, owing to *resonance*, or "sympathetic vibrations."

It has been clearly established that the various metals expand at different rates, platinum the least and zinc more than other common metals. If we made a platinum meter rod correct at 0° C., it would be 0.9 millimeters too long at 100° C., while a zinc rod would be 2.9 millimeters too long. (See "A Handbook of Useful Tables," Little Blue Book No. 835, for the metric system of weights and measures, used in all scientific work.)

EXPANSION OF LIQUIDS

In general it is found that liquids expand much more than solids. When a liter of water is heated from 0° to 100° C., it increases in volume about 40 cubic centimeters; whereas a block of steel of the same volume would expand only 3.9 cubic centimeters. Alcohol, oil, and especially kerosene expand even more than water. A pint-measure which will hold exactly 20 oz. of cold water will hold less than this amount of hot water. The expansion of water when heated causes the convection currents necessary to the action of hot-water apparatus used for warming houses.

"Liquids, like solids, expand with almost irresistible force when heated, and exert enormous pressures if expansion is prevented by their surroundings." Like solids, again, liquids expand at different rates. The behavior of water is different from that of other liquids. A bulb of water placed in a cooling bath will regularly contract in volume until its temperature falls to 4° C. Below or above this temperature it will expand and become lighter (i. e., whether it be warmed or cooled) which proves that water is most dense at 4° C. A given mass of water has, therefore, minimum volume and maximum density when it is at 4° C. (or 39.2° F.). Icebergs float on water because ice-cold water expands on solidifying—in the proportion of 100 c. c. to 109 c. c. This fact accounts for the bursting of water-pipes in houses during very cold weather.

WHY PONDS DO NOT FREEZE SOLID

This peculiarity of water has very important biological (and economic) consequences.

As everyone knows, ice is found on a pond as a crust on the surface, never all the way from the surface to the bottom. Since water at 4° C. is denser than water at the freezing point (0° C., or 32° F.), and therefore heavier, the water at this temperature would, one would think, be moved downward by convection currents, covering the bottom of the pond. But here again water forms an exception to an otherwise invariable rule. Consider the case of a pond covered with air the temperature of which is below 0° C. As the surface water is chilled it is conveyed by convection currents to the bottom of the pond until all the water of the pond is at 4° C.

But this uniform temperature cannot be maintained so long as the temperature of the air above is below the freezing point. "When the surface water is chilled to 3° C the water no longer sinks, and any further chilling of the water underneath is only effected by *conduction* of its heat upwards. This continues until the surface is at 0° C., when freezing commences. A deep pond freezes more slowly than a shallow one, because there is so much more water below the surface and at temperatures between 4° C. and 0° C., the warmth from which is traveling upwards and delaying the freezing. This peculiar property of water is of great importance in nature; for, if water had its maximum density at 0° C., instead of at 4° C., ice would form at the bottom of the pond as readily as at the surface; the pond would soon become a solid mass of ice, and fish-life would be impossible."[9]

Professor Hadley also calls attention to another noteworthy property of water; namely, that, "under suitable conditions, pure water can be cooled even to —20° C. without becoming solidified. When such "super-cooled" water is touched by a small crystal of ice, the whole mass suddenly becomes solid, and is accompanied by a marked rise in temperature."

EXPANSION OF GASES

Air is a mixture of gases, and any gas expands when heated, about nine times the volume for water, and about 20 times that for mercury. The coefficient of expansion is very nearly the same for all gases, as shown by Gay-Lussac (1778-1850) in 1802, and less accurately, earlier, by Charles (1746-1820).

Charles showed that, under constant pressure, the volume of a given mass of gas increases by a constant fraction (about 1/273—or 0.00366) of its volume at 0° C. for each increase of 1° C. in its temperature. This principle is embodied in a statement known as Charles' Law (sometimes, also, called Gay-Lussac's Law).

Naturally, the *pressure* of a gas must, if con-

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[9] Hadley, p. 226.

tained in the same space, increase with any augmentation in *volume* due to heating. Careful experiments of another French scientist, Regnault (1810-1878), showed that the pressure coefficients of various gases are the same fraction that was found for the increase of volume, and that this is nearly true in the case of all gases.

These discoveries led to important theoretical and practical consequences which I have not the space to discuss here. I may point out, however, that the world's standard thermometer at the International Bureau of Weights and Measures, near Paris, filled with hydrogen, is constructed upon the laws discovered by the three French physicists just named.

By measuring the increase of volume of a gas under constant pressure or the increase of pressure of a gas at constant volume, we have a means of measuring temperature changes.

Since the pressure of a given mass of gas increases by 1/273 of its pressure at 0° C. for each increase of one degree in temperature, at 1° C. the pressure will be 274/273 of that at 0° C. At 2° C. the pressure exerted by the gas will be 275/273; at 100° C. the pressure will be 373/273 of that at 0° C, and so on.

Conversely, at —1° C. the pressure will be diminished 1/273; that is, the gas will exert a pressure 272/273 of that at 0° C; at —2° C. the pressure will be 271/273; at —20° C. it will be 253/273, and so on.

Now, if we could continue lowering the temperature and reducing the pressure in this same way, then at —273° C. the pressure would be nothing. But before reaching such a low temperature, the gas would change to a liquid, and our method of measuring temperature by the pressure of the gas would then fail.

"Calculations based on the kinetic theory of gases lead to the conclusion that at —273° C. the rectilinear motions of the molecules would cease; which would mean that the substance was completely deprived of heat and at the lowest temperature"—i. e., *absolute zero.* The lowest temperature actually reached is —272.1° C., or 0.9° A. (Absolute Temperature—a scale proposed by Lord Kelvin in 1848).

CHAPTER III

LIGHT: ITS NATURE AND PROPAGATION

Light radiation presents to the physicist some of the most perplexing phenomena of nature. For convenience we shall define light as "that external agency which, if allowed to act upon the eye, produces the sensation of 'seeing' or of 'brightness.'"

Light-waves are generally regarded as disturbances set up in the ether by incandescent bodies, and are believed to be of the same general nature as the Hertzian waves utilized in radio work. Other invisible rays are detected by their heating or their chemical effect.[10]

In the case of the transmission of sound, the air or some other material medium is necessary; whereas light-waves pass without hindrance through a vacuum. Interplanetary and interstellar space is, indeed, an ideal vacuum. Yet we receive light and heat-rays from stars thousands of trillions of miles distant. Light-rays from our sun, some 93 million miles distant, reach us without having given up any appreciable portion of their energy to the intensely cold and black space they pass through in reaching the earth.

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[10] For information concerning the chemical, biological, and therapeutic effects of light-rays, see Shipley, "Man's Debt to the Sun", Little Blue Book No. 808.

LIGHT ADVANCES IN STRAIGHT LINES

The fact that no one can see around a corner—among other evidences—shows that, under ordinary circumstances, light advances in straight lines—possibly in the form of discrete units of energy that produce the effect of a continuous transverse-wave motion in the ether—the medium in which the waves travel. According to this view, light is simply a motion in the ether, a form of energy.

LAW OF INVERSE SQUARES

The intensity of illumination—the amount of light falling on a unit area—decreases when the distance increases. If the page of your book is not properly illuminated you must either bring it closer to the source of light or increase the intensity of the radiation. Intensity of illumination (like intensity of sound, and for the same reason) varies inversely as the square of the distance from the source of light.

Thus a cardboard screen held at a distance of one foot from a candle flame receives four times the intensity of illumination that it would receive if held at two feet, because the same amount of light is spread over a surface which has an area four times as great; hence the intensity of illumination now is only one-fourth of that obtained at a distance of one foot. At a distance of three feet, the intensity of illumination is reduced to one-ninth. So far as is known, the diminution of luminosity with distance never reaches zero. At any rate, telescopic photographs are made of stars so far distant that it requires at least a million years for the light-rays from them to reach the earth —and a ray of light travels at the velocity of nearly six trillion miles a year. "Wireless waves" travel with the same velocity as ordinary light waves—or rays. There is no essential difference between these "waves" and X-rays, excepting that the latter are of far greater "frequency" (or shorter wave-length)

TEN MILLION VOLT RAYS DISCOVERED

On November 9, 1925, Dr. R. A. Millikan, director of the California Institute of Technology, and one of the world's greatest physicists, announced before a convention of the National Academy of Sciences (meeting in Madison, Wisconsin) his discovery of rays whose frequency is 1,000 times greater than X-rays. They were described as of "the 10,000,000 volt variety," according to press reports. These rays are reported to be opposite to the rays from radioactive materials, in that while radioactivity is the result of a disintegration of atoms, the newly discovered Millikan-rays are "creative"—i. e., they build up atoms. Dr. Millikan is quoted as saying that the new rays are "100 times more penetrating than the strongest X-rays," and that they come "from nuclei of matter outside the earth, and far away in space."

"There is no prospect of utilizing the new ray for any practical purpose at present," the discoverer is quoted as stating. "With Dr. G. Harvey Cameron, my associate, study of the ray will be continued, but its development will be slow and it would be unwise to make any predictions regarding its possibilities at this time." It is quite possible that further study of these newly-discovered rays will throw new light on "The Quantum Theory" of radiant energy.

THE QUANTUM THEORY OF LIGHT

The apparent confirmation of Einstein's theory of relativity (Little Blue Book No. 408), by different experimental and observational methods (which confirmation still holds in spite of reported reversal of the Michelson-Morley experiment by Dr. Dayton C. Miller) adds to the already great importance of what is known as the "Quantum Theory of Light," first advanced in 1900 by the famous Berlin physicist, Dr. Max Planck. As the very existence of a "luminiferous ether" has been seriously called into question, it is most significant that a theory of radiant energy should be rapidly gaining ground at this time, which rejects the older conception of continuous, uniform waves of light spreading out from the point of their origin.

On the classical undulatory theory of light, the electrons of an incandescent body are represented as vibrating continuously, at a uniform rate, which would produce uniform concentric waves in the ether, with a progressive weakening of the light energy as the waves receded from their source. According to

Planck, Einstein, and many other eminent physicists, the propagation of radiant energy takes place through the emission of discrete units, or *Quanta*, the energy from a single vibration being concentrated in a definite quantity, or "bundle," called by Planck "light quantities" (*Licht Quanta*). These Quanta proceed from their source in straight lines, the motion not being necessarily continuous, but in "jumps," somewhat as bullets might be shot at irregular intervals from a machine-gun; or, better yet, as electrons are ejected from radioactive substances.

"Planck's quantum law" may be stated as follows: Particles of matter emit and absorb energy, not slowly and continuously, but in definite increments which are directly proportional to the vibration-frequency of the atom. Variation in light intensity is due, according to Planck, not to increase or decrease of light intensity, but to increase or decrease in the number of electrons—or Quanta—discharged; the various wave-lengths of the unit charges having each its own characteristic intensity. The shorter the wave-length—or the higher the frequency—the greater the light intensity of the unit. There is a progressive increase in the velocity of the Quanta from the relatively long infra-red and red rays on up to the violet and ultra-violet rays. Each wave-length, or frequency, travels with its own peculiar velocity, the shorter waves moving with the greater speed.

Under Planck's theory, as on the older hypothesis, there is an apparent weakening of the light intensity with increasing distance; but this effect is due, not to any intrinsic diminution of energy in the Quanta, but to the fact that the number of energy units met with in a given area of space becomes smaller with increasing distance from the source of emission.

It is now generally accepted—thanks to the brilliant researches of Bohr and Sommerfeld —that the emission of light pulses (Quanta) by an atom is not due to the revolution of the negatively charged electrons around the central positively charged nucleus (*proton*), but to changes in the states, or positions (orbit) of the electron in respect to the nucleus. Differing amounts of energy are imparted to an electron as it "jumps" from one orbit to another. If the change is from a "higher" (more distant) orbit to a "lower" (nearer the nucleus), light is emitted; and if the change is in the opposite direction (farther from the nucleus) light (*energy*) is absorbed.

"This light, whether emitted or absorbed, takes the form of vibrations of a definite frequency, corresponding to a sharp line in the spectrum: and the number of these vibrations per second is exactly proportional to the amount of energy required to produce the change from the initial state to the final state of the electron."[11]

Prof. D. F. Comstock ("The Nature of Matter and Electricity") calls attention to the fact

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[11] Russell, Prof. Henry Norris, "The Properties of Matter as Illustrated by the Stars", *Publications of the Astronomical Society of the Pacific*, Vol. XXXIII, No. 196, p. 279 (December, 1921).

that the Quantum Theory is not only in agreement with the partial explanations of the late Lord Rayleigh and Dr. Wien as to the relation between increasingly high temperatures and bluer light, but that it *completes* these partial explanations. In the same excellent work, Dr. L. T. Troland, of Harvard, explains that this new conception of a beam of light "means that optical images are built up on the same principle as the ordinary 'half-tone' engravings; that is, they are made up of minute dottings or stripplings far too small to be detected by the eye." He adds that "the sensitiveness of the retina is so great that a visual sensation can be produced by relatively few Quanta of the right kind of light."

For further elucidation of this very interesting new theory of radiant energy, the reader is referred to Chapter X, and to Section 54, of the work just mentioned Suffice it now to quote Professor Comstock's evaluation of the Quantum Theory:

"Planck's view has, in the minds of those most competent to judge, passed from a possibility to a probability."

And Troland adds: "It is, of course, quite possible that radiant energy is atomic while other forms of energy are not, that there will be a limit to the application of the principles of atomism to the physical universe. Indeed, certain well-known physicists still hold that even the facts which support the Quantum Theory of light can be explained without any radical change in our present doctrines. The exact outcome of this contention still rests in the balance."

Sir Joseph Thomson, of Cambridge, is working on a theory which reconciles the two apparently contradictory hypotheses.

Since the sixth century B. C., matter has been recognized as made up of minute particles, and during the past thirty years it has been known that electricity also is made up of discrete particles of energy—electrons. Energy itself, however, has until quite recently, been treated as if it were a continuous entity; that is, as if there were no lower limit to the amount of it which an atom or electron could emit or absorb. But Planck's Quantum Theory started with the assumption that in the emission of radiant energy by an oscillating atom or electron (the *resonator*), this energy is radiated in discrete Quanta or pulses. The amount of energy in a simple pulse, as previously stated, varies with the frequency (rate of vibration) of the resonator, and is shown by experiment to be proportional to that frequency. The exact energy value of this natural proportionalits consent is known as Planck's *h* (=$6.5.10^{-27}$ erg-seconds).

The fact of the matter is that, while physicists find it convenient, at least, to treat some problems on the basis of the older ether-wave theory, other observed phenomena require for their satisfactory elucidation acceptance of certain features of the Quantum Theory of Light. One professor facetiously suggests that physicists teach the undulatory theory on Mondays, Wednesdays and Fridays, and the Quantum

Theory on Tuesdays, Thursdays and Saturdays! Space limitations preclude going into the question any further here. Unfortunately, no adequate exposition of the Quantum Theory has been published which is readily within the comprehension of the "beginning" student of physics; but a number of quite recent books—and chapters in books—are available for more advanced students.[12]

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[12] For example, the following authoritative works: Planck, Prof. Max, *Die Enstehung und bisherige Entwicklung der Quantentheorie*, 1921. Dr. Planck's views were summarized by him in his Nobel Prize Address before the Royal Swedish Academy of Sciences, June 2, 1920, under the title, "The Origin and Development of the Quantum Theory". This address has been translated into English (Oxford, 1922). Cf. also Reiche, Prof. Fritz, "The Quantum Theory", London, 1922. The present status of the problems involved is fully discussed by Prof. Planck in his most recent book, "A Survey of Physics", translated by R. Jones and D. H. Williams, New York, 1925.

CHAPTER IV

SOUND

Sound has been well and tersely defined as "subjectively the sense impression of hearing, and objectively the vibratory motion which produces the sensation of sound."

In this little study we are not concerned with the physiological and psychical aspects of sound, but rather with the physical phenomena outside ourselves which excite our sense of hearing.

Sound, like heat and light, is due to vibrations. But whereas in the former we have to deal only with disturbances in the atmosphere, or in solids or liquids), in the case of light-waves the vibrations are regarded as of an etheric nature.

In any and all of these phenomena, whether of light, heat, or sound, the cause of the disturbance or vibrations, whatever the source may be, is a tremor or agitation, or motion to and fro, of the molecules of which the substance of the source is composed.

In many cases, it is possible to follow with the eye the motions of the particles of the body causing the sound, or the motion—or commotion. Vibrations of a glass jar or other object may be felt by the tip of the finger if applied lightly; though a firm grasp of the vibrating body will act as a "damper," and the vibrations will cease. The same is true of a sounding bell. A light ball or a hollow bead hung on a tuning-fork by a fine thread will be set violently in motion. If we touch the surface of water with the prong of a sounding tuning-fork the water splashes up in spray. If we sound a tuning-fork and then touch the fork to the lips, we feel its vibratory motion.

Sound, then, often consists of vibrations which can be *felt* as well as *heard*. What is transmitted is nothing more or less than a mode of motion, called a wave. When these waves strike against the tympanum or ear-drum, we have the sensation of hearing. But, physically speaking, the sound (vibrations) would exist whether we *heard* them or not. A totally deaf person could not hear a peal of thunder; but, given the disturbance, the atmospheric vibrations would be in motion just the same.

Usually air is the medium through which sound travels; but the well-known air-pump experiment shows that sound may travel through solids; and tappings on the sides of a tub with the ears submerged in the water can also be heard. If two stones be struck together under water, the sound perceived by an ear under water is louder than if the experiment had been performed in the air.

But sound-vibrations cannot be conveyed to the ear unless matter of some sort fills all the intervening space between the ear and the source of the vibrations. In the air-pump experiment, an electric bell is suspended in the receiver of the pump, and the wires conveying the current pass through an air-tight cork closing the hole at the top of the receiver.

"These wires form a material channel from the bell to the outside air, but if they are fine the sound which they carry is hardly appreciable. If while the air within the receiver is at atmospheric pressure the bell is set ringing continuously, the sound is very audible. But as the air is withdrawn [it cannot *all* be withdrawn] by the pump the sound decreases, and when the exhaustion is high the bell is almost inaudible" (J. H. Poynting). Before exhaustion, the sound travels through the glass of the receiver and the base plate, which proves that these substances convey sound-waves.

VELOCITY OF SOUND IN AIR

Anyone who has traveled by water has noticed how the steam from a distant steamboat whistle is seen quite a few moments before the sound is heard. And during electrical storms the peal of thunder follows a few seconds after the lightning-flash is seen, the light from the latter reaching us instantaneously, while the thunder takes time to travel. The more distant the flash, the longer the interval is between the lightning and the sound of the thunder. The distance of the lightning can be calculated by allowing a mile for every five seconds between flash and peal. Light travels with a velocity of 186,300 miles per second, but sound-waves in air travel, on a warm summer day, at about 1,120 feet per second. Sound travels faster on warm days than on cold, because warm air is less dense than cold air. On a frosty day the velocity of sound may be as low as 1,080 feet per second.

The earliest determination of the velocity of sound was made in France, in 1738. But it was not until 1822 that satisfactory experiments were carried out, by a commission appointed by the French Academy.

It was found that the velocity of sound in air at a temperature of 15.9° C. is 1118.15 feet per second. The velocity increases at 60 cm. per second for a rise of 1° C. At 0° C. the velocity is 331.4 meters per second, as compared with 340.9 meters (1118.15 feet) with a temperature of 15.9° C. Later experiments do not give results materially differing from those obtained in 1822.

Greely found the velocity of sound-waves to be 305.6 m. (1002 feet) at a temperature of —45.6° C. (—50° F.)—the lowest velocity so far measured. The highest known velocity is 1,240 feet per second at a distance of 100 feet from a ten-inch gun—which is 22% above normal. For all distances above 500 feet from the gun the velocity of the explosive sound from even the largest sized gun is practically normal.[18]

Generally speaking, a feeble sound and an intensely loud sound travel through the air with the same velocity. They differ from each other, however, in *amplitude* of movement of the air through which the sound-waves are conveyed, and perhaps in the wave-length. The *distance* a sound can be heard depends upon the intensity of the disturbance—whatever the cause. The noise caused by the eruption of the Krakatoa volcano (on a small island between Java and Sumatra) in 1883, was heard four hours after the explosion occurred, at a distance of 2,900 miles to the southwest (at Rodriguez). The sound-wave itself completely encircled the earth, being registered (photographically) by barometers throughout its course.

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[13] Merchant and Chant, p. 152.

RELATION BETWEEN VELOCITY, WAVE-LENGTH, AND FREQUENCY

When a stone is dropped into a quiet pool or smooth pond, a disturbance is produced which extends over the surface of the water in circles centered at the place where the stone struck. The waves or ridges following expand into ever widening circular swells, following one after the other, each separated by circular troughs, the ridges or waves becoming less pronounced as the circles grow larger. This latter effect is due to the fact that the energy in the swells becomes spread over a larger circumference.

Likewise, a sound-wave in the air loses in "amplitude" when spread over an ever widening area; hence a sound appears to be more feeble when the distance from the source of the disturbance is increased. The amplitude of the waves is dependent on the violence (or loudness) of the sound or cause of the disturbance, but the velocity of propagation is virtually always the same at a given atmospheric temperature. The amplitude of the wave corresponds to the distance each particle of air moves to and fro from its original position.

By *velocity* of sound-waves is meant the distance which a crest travels in one second. The number of crests passing a fixed point in one second is called the *frequency;* and the time it takes for one wave to pass a given point—that is, the time between crests, is called the *period* of the wave-motion. The distance between two corresponding points in any two adjacent waves is called *wave-length.*

It is, of course, only the wave-form that passes over the surface of the water, not the water-particles themselves. This is true also of sound. Nothing material passes from the source of a sound to the ear of a hearer. What travels is the wave-motion of the air, or the vibratory oscillations of the molecules in liquids or solids. Sound-waves are longitudinal or compression waves, made up of alternate *condensations* (crests) and *rarefactions* (troughs). The circular waves sent out by the vibrations of a bell (for example) are spherical waves, made up of alternate spherical shells of compressed and rarefied air, traveling out in ever widening concentric circles in every direction in space.

PITCH

The "pitch" of a musical note (its place on the musical scale) depends entirely upon the *frequency* of the sound-waves reaching the ear —the frequency, as said, being the number of complete waves arriving in one second.

"A musical tone is due to rapid periodic motion of a sounding body; a noise is due to non-periodic motion."

In some cases, a number of notes, each of which heard separately is musical, become when heard together mere noise, an irregular succession of shocks, the periodic nature of the vibrations being destroyed by the jumble of sounds. However, not all vibrations, even though periodic, produce recognizable sounds, musical or otherwise.

LIMITS OF AUDIBILITY—RANGE OF HUMAN VOICE

For ordinary ears, the lowest frequency which causes the sensation of a musical tone is about 30 per second, while the highest is between 10,000 and 20,000 per second. The range of an ordinary piano is from 40 to 4,000 vibrations per second, and the range of the human voice lies between 60 and 1,300 vibrations per second, more than four and a half octaves. A good singer has about two octaves.

CHAPTER V

ELECTRICITY AND MAGNETISM

From the time of Thales of Miletus, who, as early as 600 B. C., called attention to the fact that the yellow resinous fossilized substance known as *amber* would, when rubbed, attract light objects, down to the days of William Gilbert (1540-1603), no distinction was made between what we now distinguish as *magnetization* and *electrification.*

Amber was called by the Greeks *elektron.* When Gilbert discovered that many other substances showed like phenomena of attraction, when rubbed, he called them all "electrics," since they were all "amberous." A glass rod rubbed with silk acts in the same way as a stick of sealing-wax or rod of hard rubber when rubbed with flannel or cat's fur. If we comb our hair vigorously on a cold, dry day, the comb will then support long chains formed of bits of paper. Under similar conditions, a cat's fur, if rubbed by the hand, will emit sparks, visible in a darkened room. These, and similar phenomena, are all *electrical* in nature, not *magnetic.* They are due to what we know as *static electricity.*

Magnetization, on the other hand, is a very different phenomenon. While electrification can be produced by rubbing almost any substance, especially non-metal, magnetization can be produced *only* in metals, and in three metals only—i. e., iron, nickel and cobalt—with the exception of a series of alloys composed of copper, manganese, and aluminum. Whereas a metallic body electrified by friction will not ordinarily have its properties localized in spots, a magnetized body *always* has at least two poles where its magnetism is more or less concentrated. These poles are designated as "North" and "South," and *like magnetic poles repel, unlike attract, each other.* But unmagnetized iron or steel will be attracted by both ends of a magnet.

While the magnets of commerce and industry are, for the most part, artificial products—magnetized steel—a natural magnet (an ore of iron—Fe_3O_4) has been known at least since the days of the early Greeks, and given the name *lodestone* (i. e., leading stone). This ore was once very abundant in Asia Minor, and the name is derived from the town of Magnesia, in Lydia, near which town the ore was mined. (See my "Greek Physics and Modern Science," Little Blue Book No. 837). This ore is now known as *magnetite*, a compound of iron and oxygen.

If a specimen of magnetite be dipped in iron filings, the iron will cling to it, and if the ore be suspended by an untwisted fiber, it will come to rest in a definite position, indicating a certain direction—hence the name "leading-stone" or lodestone. Like all other magnetized bodies it has two unlike poles, one of which attracts the north-seeking end of a compass, while the other end repels it. There are, then, two kinds of magnetic poles just as there are two kinds of electricity.

The peculiar attractive and directive properties of magnetized iron and steel are highly important in their practical application—e. g., in the manufacture of the pocket-compass, compasses of ships, the action of dynamos, motors, telegraph and telephone instruments, and of the chief appliances for measuring electric currents. Steel magnets are much more powerful and far more convenient to handle than natural ones, and are always preferred in experimental work.

Any piece of steel which has been stroked by a natural magnet becomes itself a magnet. The same result may be obtained by placing the steel within a coil of wire carrying a current, as was shown by Ampére (1775-1836), and by Arago (1786-1853). The latter, in 1820—a year after Oersted's discovery of the effect of an electric current in the magnetic needle—proved that a wire carrying a strong current had the power to lift iron filings, and must therefore be recognized as a magnet. Sturgeon, in 1825, was the first to show that if a core of soft iron is introduced into such a coil the magnetic effect is increased, and that the core loses its magnetism when the circuit is open. The combination of the helix of insulated wire with a soft-iron core is called an *electromagnet.*

"When the helix is used without a core, the greater number of the lines of force pass in circles around the individual turns of wire, comparatively few running through the helix from end to end and back again outside the coil; but when the iron core is inserted, the greater number of lines of force pass in this latter way, because the permeability of iron is very much greater than that of air. Whenever a turn of wire is near the core, the lines of force, instead of passing in closed curves around the wire, change their shape and pass from end to end of the core. The effect of the core, therefore, is to increase the number of lines of force which are concentrated at the poles and consequently to increase the power of the magnet. . . . The strength of an electromagnet depends equally on the strength of the current and on the number of turns of wire which encircle the core."[14]

No sooner were the principles of electromagnetism discovered than they were followed by practical applications.[15] In 1831, Joseph Henry (1799-1878)—co-discoverer with Faraday of the laws of electromagnetic induction—used an electromagnet at Albany Academy, New York, for producing audible signals. Henry transformed the feeble electromagnet of Sturgeon into an instrument capable of lifting a weight of 3,500 pounds. In 1916, Dr. E. W. Rice, Jr., then president of the General Electric Company, said, "I may say at once, without fear of successful contradiction, that the entire electrical industry is not only founded upon, but is a direct outgrowth of the work of Henry." For a most interesting and informative appreciation of this great American physicist, see *Science*, November 6, 1925 (Vol. LXII, No. 1610).

In 1837, Samuel F. B. Morse devised the system by which dots and dashes, representing letters of the alphabet, were made on a strip of moving paper by the action of an electromagnet. The possibility of producing rotary motion by the action of electromagnets was, at about this same time, demonstrated by the experiments of Henry, Jacobi, Davenport, and others.

It was in 1876 that Alexander Graham Bell announced to a scoffing world that the human voice could be transmitted by electricity, by employing the principle of induced currents for reproducing sound-waves. The essential part of this apparatus was a hard rubber case containing a permanent bar-magnet—a U-shaped

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[14] Merchant and Chant, pp. 440-441.

[15] The story of these discoveries is told in my "Principles of Electricity", Little Blue Book No. 133.

type is now employed—around each pole of which was wound a coil (with many turns) of a very fine insulated wire. In this "Bell receiver" a disk of thin sheet-iron is supported in such a way that its center does not quite touch the ends of the magnet. A hard rubber cap or earpiece with a hole in the center holds the disk in place. The transmitter was at first just like the receiver, an iron diaphragm in each case being supported in front of one end of the bar-magnet. The terminals of the transmitter and receiver coils were, of course, connected by the line wires.

Sound waves falling upon the diaphragm of the transmitter cause it to vibrate, and these vibrations produce fluctuations in the number of lines of force passing through the coil, which, in turn, cause induced currents to surge to and fro in the circuit. The currents alternately strengthen and weaken the magnet of the receiver and thus set up vibrations in the diaphragm similar to those in the diaphragm of the transmitter.

With the substitution of the horse-shoe type of magnet for the bar-magnet, the Bell *receiver* is still used on all telephone systems; but the original *transmitter* has been displaced by one of the microphone type. It contains a shallow round brass box filled with loosely packed granules of hard carbon, resembling coal-dust in appearance. The front and back of the box are polished plates of carbon, and the sides of the box are insulators. The front carbon is attached to the center of the soft iron diaphragm, and moves in and out a little when the diaphragm vibrates. The other plate is fastened rigidly to the solid back of the case.

"The transmitter acts on the principle that the conductivity of the granular carbon varies with the varying pressure exerted upon it, as the diaphragm vibrates under the action of the sound-waves." A current from a battery (a large storage battery or a dynamo at the central station) flows through the diaphragm to the front plate, and then back through the granules of carbon to the other plate and then out along the telephone line to a receiver.

"When the diaphragm moves back a little, it compresses the granules, their resistance decreases, and the current gets stronger and pulls the diaphragm of the receiver back also. When the transmitter diaphragm moves out, the current decreases and the receiver diaphragm moves out also. So all the motions of the transmitter diaphragm are reproduced by the receiver diaphragm. If one speaks into the transmitter, causing its diaphragm to move in a corresponding way, the receiver diaphragm moves in the same way and produces the same kind of waves in the surrounding air."[16]

THE ELECTRIC CURRENT

Down to the time of Aloisio Galvani (1737-1798—a physician and professor of anatomy in the University of Bologna—friction and induction were the only methods known for producing electricity. Galvani discovered, quite by accident, that the discharge of an electric machine connected with a skinned (dead) frog produced twitching in the legs. On further experimentation, he discovered that the same convulsive movements of the frog's legs could be produced without a discharge from his electric machine, merely by touching one end of a branched fork of copper and silver wires to the muscles of the leg and the other end to the

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[16] Black and Davis, pp. 314-315.

lumbar nerves. This result Galvani erroneously attributed to "animal magnetism."

Alessandro Volta (1745-1827), professor of physics at the University of Pavia, upon investigating the problem, arrived at the correct conclusion that the electric current had its origin, not in the frog, but in the contact of the metals. In the course of his researches Volta found that when disks of copper and zinc were separated by a disk of cloth moistened with salt brine, and joined externally by a conductor, a continuous current of electricity passed through the circuit. He thus invented a *chemical* method of producing electricity continuously. Later, he substituted zinc and copper strips for the disks and immersed them in dilute sulphuric acid, thus giving to the world what is now known as the *Voltaic Cell*, or the *Galvanic Cell*. When several cells are combined they constitute a *battery*, which gives rise to a stronger (continuous) current of electricity.

For the nature and terminology of electricity, space limits require that I once more refer the reader to my "Principles of Electricity." One further consideration, however, should be brought to mind.

It is interesting to reflect upon the fact that if we could reduce the temperature to absolute zero (—273° C., or —459° F.), all molecular movement would cease—but not electronic movement; no chemical action could take place; all electrical resistance would disappear; and electric currents (if these were possible under the circumstances) would go on, presumably, forever. Hence the law that *electrical resistance of pure metals decreases with progressive lowering of temperature;* and the law (Curie's law) that *magnetic susceptibility is inversely proportional to the absolute temperature.*

Prof. Kamerlingh Onnes, of Leyden, Holland, has shown that the resistance of pure mercury at —270° C. is less than one ten millionth of its resistance at 0° C. Professor Onnes has produced a temperature within 1° of absolute zero; that is, he has produced a temperature 272° below the freezing point of water. At —273° C.—one degree less than that already obtained—the atoms and molecules would be packed together in an absolutely inert mass, and all vibrations of the molecules and atoms would cease

What would happen then? No one knows for a certainty just what would happen.

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