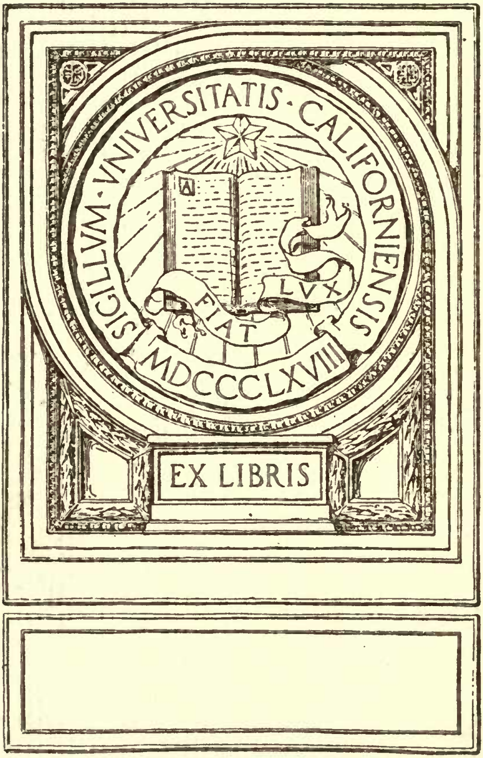
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A

TREATISE ON FUEL

SCIENTIFIC AND PRACTICAL

Brown

BY

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ETC. ETC.

WITH ILLUSTRATIONS

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I Dedicate this Work

TO

THE LADIES AND GENTLEMEN

I HAVE HAD THE PLEASURE OF INSTRUCTING

DURING MY TWENTY-THREE YEARS' RESIDENCE IN DUBLIN.

THEY HAVE LARGELY CONTRIBUTED TO

THE PLEASURES OF MY LIFE

BY THE ZEAL AND EARNESTNESS WITH WHICH THEY SECONDED

MY EFFORTS, AND BY THE HEARTY

KINDNESS AND SYMPATHY THEY HAVE EVER SHOWN ME ;

AND I AVAIL MYSELF OF THE OPPORTUNITY

OF THANKING THEM,

AND WISHING THEM EVERY HAPPINESS AND SUCCESS.

ROBERT GALLOWAY.

PREFACE.

The Lectures I gave on Fuel in the Royal College of Science, Dublin, form the basis of this book. The book is intended for the use of Students in the Higher Schools and Colleges of Science, as well as for Manufacturers. I believe both Students and Manufacturers will find it a useful one; no doubt some who consult it may think that some branches of the subject, which have been omitted, ought to have been introduced; other branches have necessarily come under my consideration in preparing the work for the press; but I thought it desirable not to extend the book to an undue length, and to avoid what is technically termed book-making.

I am indebted to my friend and former Student, Mr. C. C. Hutchinson, for the excellent drawings;

and for the revision and extension of the "Mathematical Formulæ," my late friend and Student, Mr. C. C. Bateman, LL.D., so kindly prepared for my "Second Stepin Chemistry." I am also greatly indebted to Mr. Hutchinson for assisting me in reading the proofs.

ROBERT GALLOWAY.

DUBLIN, *November*, 1879.

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CHAPTER I.

Fuel Substances. The Physical and Chemical Properties of various kinds of Fuel. The Classification of Coal generally adopted. The Gases occluded in Coal. Weathering of Coal. Spontaneous Ignition of Coal.

THE different substances which are practically employed for the production of heat are termed *fuel*; they consist of woody tissue in an unaltered or an altered form; or they are substances derived from it by natural or artificial means. Wood is unaltered woody tissue, containing, in addition, water and inorganic substances; the latter constitute the ash. Peat is woody tissue slightly altered, and the different varieties of coal are still more altered forms of it. Peat and coal contain, like wood, variable proportions of ash and water, in addition to the organic or combustible portion. These different altered forms of the tissue have been brought about by natural operations. Other forms of fuel are products obtained from wood or its altered forms by artificial processes, as charcoal, coke, liquid and gaseous hydrocarbons, &c. Liquid and gaseous hydrocarbons are also produced from coal by natural means.

WOOD, when submerged and exposed to a certain temperature, and brought in contact under these conditions with the small amount of oxygen contained in the water, absorbs a portion of that element, carbonic anhydride (CO_2), marsh gas (CH_4), and water are formed by the oxidation. We may, from a knowledge of these facts, explain *theoretically* the conversion of wood into *peat, lignite* and the other varieties of coal. In the passage of the wood into these other forms of fuel the proportion of carbon, as shown in the following equations, *decreases* less relatively than the hydrogen and oxygen; and the oxygen *decreases* more rapidly than the hydrogen; so that the proportion of the latter element in *excess* of the quantity required to form water with the oxygen keeps *increasing* as the change of the tissue progresses, until anthracite, the ultimate product of the conversion, is reached. It is considered that of the hydrogen in the fuel it is only the *excess* quantity that is available as a source of heat. The Germans apply to the *excess quantity* the term *disposable* hydrogen; as this is a suitable term, it is employed in this work.

(1) $4C_{34}H_{48}O_{22}$ (wood) + $12O = 4C_{20}H_{22}O_8$ (peat) + $24CH_4 + 32\,CO_2 + 4H_2O$.

(2) $4C_{34}H_{48}O_{22} + 4O = 4C_{27}H_{28}O_7$ (lignite) + $8\,CH_4 + 20\,CO_2 + 24\,H_2O$. 14

(3) $4C_{34}H_{48}O_{22} + 8\,O = 4C_{26}H_{20}O_2$ (cannel coal) + $8\,CH_4 + 24\,CO_2 + 40\,H_2O$. 16

(4) $4C_{34}H_{48}O_{22} + 10O = 2C_{40}H_{16}O$ (anthracite) + $24CH_4 + 32CO_2 + 32H_2O$.* 14

These equations are taken from the late Dr. Miller's work on Organic Chemistry; the formulæ given are empirical; that for wood is founded upon an analysis of oak; the formula for *pure cellulose,* the organic tissue of wood, is somewhat different, being $C_{12}H_{20}O_{10}$; it contains, as shown by the formula, no *disposable* hydrogen. It may be as well to observe that in all fuel containing oxygen, as well as carbon and hydrogen, the proportion of hydrogen may be sufficient or more than sufficient, but never less in quantity, than is required to form with the oxygen water.

The preceding views with regard to the transformation of wood into coal are purely theoretical. The following Table, taken from Dr. Percy's work on fuel, is more instructive; it exhibits the gradual passage of vegetable matter into anthracite, or that variety of coal which consists almost wholly of

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* The conversion of wood into coal may take place, according to Bischof, in four different ways, viz:—

(1) By the production from the wood of CO_2 and CH_4
(2) By the " " " CO_2 and H_2O
(3) By the " " " CH_4 and H_2O
(4) By the " " " CO_2, CH_4, and H_2O

carbon; the proportion of that element is estimated in the Table at the constant amount of 100:—

Illustration of the Gradual Passage of Woody Tissue into Anthracite.

	Carbon.	Hydrogen.	Oxygen.	Disposable Hydrogen.
Wood—average of 26 varieties . . .	100	12·18	83·07	1·80
Peat	100	9·85	55·67	2·89
Lignite—average of 15 varieties . . .	100	8·37	42·42	3·07
Ten Yard Coal of Staffordshire Basin	100	6·12	21·23	3·47
Steam Coal . . .	100	5·91	18·32	3·62
South Wales Coal Pentrifelin . .	100	4·75	5·28	4·09
Anthracite from Pennsylvania, U.S. .	100	2·84	1·74	2·63

Charcoal and coke are fuels produced artificially, they consist essentially of carbon, but they contain some hydrogen and oxygen; also nitrogen, sulphur, and the inorganic matter (ash) of the substances from which they were prepared. Charcoal is obtained by charring or carbonising wood; peat also yields a charcoal, and coke is obtained by a like process from coal. By the charring, the water and the gaseous products (formed) are expelled; the charcoal or coke contains more carbon than the

Average Elementary Composition of Wood, Peat, and different Varieties of Coal in the Dry State.

Fuel.	Specific Gravity.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Coke.
Wood	1·46	50·	6·5	40·5	1·0	—	2·0	30·
Peat*	—	58·75	6·56	34·69	—	—	—	—
Boghead Coal . .	1·19	65·5	9·1	5·6	0·7	0·1	19·	42·
Cannel " . .	1·27	80·1	5·5	8·1	2·1	1·5	2·7	60·
Coking " . .	1·27	81·4	5·8	7·9	2·0	0·7	2·0	67·
Cherry " . .	1·26	84·0	5·0	8·8	—	—	1·7	—
Anthracite . . .	1·39	90·4	3·3	3·0	0·8	0·9	1·6	92·
	1.276.	80.28	5.74	6.68	1.12	2.4	5.4	59.2

* In the calculation of the quantity of carbon, hydrogen, and oxygen in the peat, the ash has been excluded and the nitrogen is given along with the oxygen, although that is not specified in the Table.

fuel from which it was obtained, and it has, weight for weight, a higher calorific value, as we shall hereafter explain, than the original fuel. Coal loses on an average in coking one-third in weight, and increases one-tenth in bulk.

THE PHYSICAL AND CHEMICAL PROPERTIES OF VARIOUS KINDS OF FUEL.

WOOD.—Carbon, hydrogen, oxygen, and ash are* the constituents of wood; it also contains water; when recently felled it contains a large quantity, which varies in amount with the nature of the tree, the part of the tree, the season of the year at which it was felled, and, in trees of the same kind, with the place of their growth. When it becomes perfectly air-dried, it contains from 18 to 20 per cent. of moisture; a point of great importance in its employment as fuel, as will be seen in the portion of the work devoted to the calorific power of fuel. Another matter of great importance as regards its value as fuel, is the small quantity of *disposable* hydrogen it contains.

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* Cellulose, the organic tissue of wood, contains, as shown by its formula, no nitrogen; but as the sap of all plants contains albumen and other nitrogenous matter, there must be from this source a small amount of nitrogen present in wood, and also a correspondingly small amount of sulphur in addition to the sulphur which exists as sulphate in the ash.

TABLE

Showing the percentage of Water in different kinds of Fresh-cut Wood.

Name of Wood.	Water.	Name of Wood.	Water.
Hornbeam . . .	18·6	Pine	39·7
Willow	26·0	Red Beech . . .	39·7
Sycamore . . .	27·0	Alder	41·6
Mountain Ash . .	28·3	Aspen	43·7
Ash	28·7	Elm	44·5
Birch	30·8	Red Fir	45·2
Wild Service Tree	32·3	Lime Tree . . .	47·1
Oak	34·7	Italian Poplar . .	48·2
Pedicle Oak . .	35·4	Larch	48·6
White Fir . . .	37·1	White Poplar . .	50·6
Horse Chesnut . .	38·2	Black Poplar . .	51·8

Proportion of OH_2 in Wood at different Periods of the Year.

Woods.	At the end of January.	At the end of April.
Ash	28·8	38·6
Sycamore	33·6	40·3
Horse-Chesnut . .	40·2	47·1
White Fir	52·7	61·0

Difference in the Desiccation of Barked and Unbarked Wood by exposure to air.

	Loss per cent. of the original weight of the Wood.			
	July.	August.	September.	October.
Barked Stems .	34·53	38·77	39·34	39·62
Unbarked Stems	0·41	0·84	0·92	0·98

Amount of Water expelled from Air-dried Wood at Gradually Increasing Temperatures.

	Water expelled from 100 parts of Wood.				Remarks.
Temperature of Dessication.	Oak.	Ash.	Elm.	Walnut.	
125° C.	15·26	14·78	15·32	15·55	Between 200° and 225° there is slight decomposition, and water alone is not evolved. The statement, in works on Chemistry, that wood contains a given quantity of OH_2 can only be exact in so far as they indicate the degree of desiccation.
150° C.	17·93	16·19	17·02	17·43	
175° C.	32·13	21·22	36·94	21·00	
200° C.	35·80	27·51	33·38	41·77	
225° C.	44·31	33·38	40·56	36·56	

The amount of ash in wood varies between 0·2 and 5 per cent., according to the kind of wood and the nature of the ground upon which the tree has grown; it usually amounts to one per cent. The specific gravity of all woods, it is found, is nearly the same, when the determinations are so made that the *pores* are completely deprived of air and filled with water.

Specific Gravity of different kinds of Wood.

Name of the Wood.	Specific gravity.		Percentage of Water.	
	Freshly felled.	Air dried.	Fresh felled.	Air dried.
Common Oak	1·0754	0·7075	34·7	16·64
Pedicle Oak	1·0494	0·6777	35·4	
White Willow	0·9859	0·4873	50·6	
Beech	0·9822	0·5907	39·7	18·56
Elm	0·9476	0·5474	44·5	18·20
Hornbeam	0·9452	0·7695	18·6	
Larch	0·9205	0·4735	48·6	
Scotch Fir	0·9121	0·5502	39·7	
Sycamore	0·9036	0·6592	27·0	18·63
Ash	0·9036	0·6440	28·7	
Birch	0·9062	0·6274	30·8	19·38
Mountain Ash	0·8993	0·6440	28·3	
Fir	0·8941	0·5550	37·1	17·53
Silver Fir	0·8699	0·4716	45·2	
Wild Service	0·8633	0·5910	32·3	
Horse-Chesnut	0·8614	0·5794	38·2	
Alder	0·8571	0·5001	41·6	
Lime	0·8170	0·4390	47·1	18·97
Black Poplar	0·7795	0·3656	51·8	
Aspen	0·7654	0·4302	43·7	
Italian Poplar	0·7634	0·3931	48·2	19·55
Ground Willow	0·7155	0·5289	60·0	

PEAT.—This fuel varies in composition and texture according to the extent of the decomposition or decay of the vegetable matter it is derived from, has undergone. When air-dried its specific gravity ranges from 0·25 to 0·9, or even to above 1·0. When fresh from the bog it may contain, if fibrous, 90 per cent. of water, of which from 50 to 70 per cent. is removed by air-drying; the proportion of water is considerably less in the denser kinds. In samples of black turf taken from a depth of twelve feet in the bog, and three or more from the bottom of the bog; and samples of red turf taken from within three feet of the surface which Mr. R. Mallett, F.R.S., experimented on some years ago in Ireland; he found that when air-dried they each lost on being further dried for four days in a stove or kiln, at a temperature of 180° F., or thereabouts, the following percentages of water: the black, 34·8 per cent.; and the red, 19 per cent. The black turf, therefore, when air-dried retains nearly twice the moisture in proportion to its weight that red turf does—the former holding about one-third, and the latter about one-fifth of their respective weights of moisture. Both sorts of turf, after being thus dried, were left exposed to the air under cover of a roof for a period of at least five weeks in the months of October and November. The specimens were afterwards weighed to see how much water they had reabsorbed. The black turf had reabsorbed 7·14 per cent., and the red 4·87 per cent.; the black had, therefore, only reabsorbed about one-fifth of the water it had lost in kiln-drying, and the red had reabsorbed about one-fourth.

The ash peat contains is not in all cases wholly derived from the plants from which the peat has been produced, a part has been deposited in it from the water which has percolated it; the quantity is therefore variable. The average proportion is from 1 to 2 per cent., but it may vary from 1 to 30 per cent.

Peat cannot be economically substituted for coal where the price of the latter is, as in Great Britain, relatively low; its bulky nature, the large amount of water it retains, even after being thoroughly air-dried, renders the carriage of it costly and reduces its available heating power. It is a more costly fuel in these countries than coal, if the quantity of each of the two fuels that would be required for a given amount of work were compared.

Coal.—This is by far the most important of the substances used as fuel. What is coal? might appear to the public a very absurd question to ask. Nevertheless, whether the mineral called boghead cannel is, or is not, a coal gave rise to a remarkable trial, which took place at Edinburgh in 1853 before the Lord Justice-General and a special jury, an abstract of which is given in Appendix A. It is difficult, as was proved at that trial, to frame a precise definition of the term coal either in a commercial or scientific sense. This arises from the fact that the substances, classed under the term coal, are altered vegetable matter in various stages of alteration and decomposition, varying from *lignites*, some of which resemble wood and peat, up to *anthracite*, which contains 90 per cent. or more of carbon, and which might be regarded from its chemical composition as coke naturally produced; hence the substances which are termed "coal" differ very much from each other both in physical and chemical characters.

The real value of a coal for fuel depends on its calorific power, and on certain accessory properties, as for instance its greater or less cohesiveness, the proportion and the chemical character of the ash, and whether the coal *cakes* or not under the influence of heat. It consists of, in varying proportions, carbon, hydrogen, oxygen, nitrogen, sulphur, the incombustible or inorganic portion (ash) and water. The water may be expelled at a temperature slightly above 100°; the nitrogen ranges pretty constantly between 1 and 2 per cent. It is derived no doubt from the nitrogenous matter which existed in the sap, &c., of the original plant. The sulphur may exist in the ash as a sulphate, but it exists frequently in the largest amount in combination with iron, in the form of iron pyrites (FeS_2), and it exists no doubt to a small extent as a constituent of the organic portion of the coal, being derived from the albuminous bodies which were present in the sap of the plant.

Some coals contain only 1 per cent. of *ash*, others contain such a large amount as to be unfit for fuel, and to become transformed into bituminous shales. The ash in many coals has not been solely derived from the original plants, but has been carried and deposited in the coal, during its formation, by water and other agencies. Its colour is sometimes *white*, and at other times *red*. The redness is due to an excessive quantity of iron pyrites in the coal; the iron, during the burning of the fuel, becoming converted into ferric oxide (Fe_2O_3). The combustibility and value of the coal depends not only upon the amount, but also on the nature, of the ash it contains; iron pyrites, for example, in burning corrodes and destroys the fire-bars. A *ferruginous* and *calcareous* ash is fusible, and consequently incrusts and sticks to the furnace-bars under the form of slag and clinker, thus impeding the combustion, and requiring also an extra expenditure of manual labour from the stoker;* *argillaceous*, or *siliceous* ash, on the other hand, remains pulverulent, and impedes the combustion much less than the ferruginous and calcareous ash.

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* Sometimes a bed of clinker is expressly formed, and made to serve an important purpose. Thus in furnaces in South Wales and some other localities such a bed is ingeniously used as a substitute for a grate, on which small and inferior coal may be profitably consumed.

The comparative freedom of the ash from phosphorus is of great practical importance in iron smelting.

The minor varieties of coal are numerous; fully a hundred different kinds, it is said, are sent into the London market. The more important kinds may be divided into the four following classes:—

1. Lignite, or brown coal.
2. Bituminous coal.
3. Cannel coal.
4. Anthracite.*

LIGNITE.—Geologists apply this term to those carboniferous minerals which occur in later deposits than the true coal measures. They have frequently the structure of wood, but many of them are free from ligneous texture. They vary in physical characters, from that of the more compact peats to that of the bituminous coals; they therefore present a great variety of aspects; "some, being almost as hard as true coal, are known as 'stone coal;' others, being distinctly woody, are known as 'wood coal;' some, again, consisting of thin layers like compressed leaves, are called 'paper coal;' whilst soft earthy varieties have received the name of 'peat coal.'" They differ from true coals

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* The industrial classification by M. L. Gruner is given in Chapter III.

in the large proportion of moisture they contain. When they are first raised they contain as much as 40 per cent., and even after long exposure to the air they may contain from 15 to 20 per cent., and if deprived of this water by desiccation,* they will, if subsequently left exposed to the air, reabsorb the amount they lost—in this respect resembling wood. No analyses of this kind of fuel should be accepted which does not indicate the proportion of water. The sp. gr. of the different varieties ranges from 1·1 to about 1·4. Their colour varies in shade from brown to black, and in lustre from dull to shining. The amount of ash they contain varies from 1 to 50 per cent.; in most cases, however, it is not less than 5 and seldom above 10 per cent. Iron pyrites is very frequently, if not always, present in lignites.

Lignite is generally non-caking—that is, its *powder*, when heated to redness in a close vessel, does not yield a coherent coke; varieties of it have been found so rich in resin as to cause it to cake from that cause alone.

Bituminous Coal.—This variety is the most valuable and most abundant of the English coals, and it constitutes the bulk of the immense coal-fields of North America. It occurs above the old red, and beneath the new red, sandstone, in what

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* The water is expelled from lignite on exposing it to 100° C. or somewhat higher temperature.

geologists have termed, from its presence, the "coal measures." The term bituminous has been applied to this variety of coal, not from the coals of this class containing any bitumen, but because, like bitumen, they burn with a more or less smoky flame. That they contain no bitumen is proved by their insolubility, as only a mere trace dissolves, in benzole, ether, and like solvents in which natural bitumen dissolves. By some writers the term *bituminous* is used to denote the matter which is *volatilised* when a coal is heated to redness in a close vessel, and in that sense it is synonymous with *volatile* matter, both terms being employed indiscriminately. *Flaming*, as Dr. Percy remarks in his work on fuel, would not be a bad substitute for the word bituminous.

The passage of bituminous coal into anthracite is as gradual as that of lignite into the bituminous kind, so that there is no precise line of demarcation between these classes of coal. Hence in the class bituminous, many varieties of coal are included, which, in external characters, and ultimate chemical composition, differ widely from each other. "The character of coals of the bituminous class may be summed up as follows:—They are easily frangible, and opaque, *except* in thin slices; dull, shining, or fatty in lustre; black or brown-black in mass, but brown when in the state of fine powder; some soil the fingers, and others do not; they are variable in hardness, even, conchoidal, or uneven, in fracture, frequently breaking into pieces more or less cubical or rhombic; they generally exhibit cleavage, due to bedding or pressure, but never crystalline structure; they generally contain only a small proportion of water. In open fire-places, or in furnaces of ordinary construction, they burn with a more or less smoky flame; and when heated to redness in a close vessel, they leave a solid, carbonaceous, more or less coherent coke, which contains the fixed inorganic matter, or ashes." (*Percy.*)

The most important practical classification of bituminous coals is the divison of them into *caking* or *coking coals*, and *non-caking* or *free-burning* coals.

Caking coals, when heated to the degree at which they decompose, partially fuse, and become pasty; gaseous matter is evolved, which burns with a bright flame, and the non-volatile matter swells and forms a spongy mass. The fine powder of such coal yields, when heated to redness in a close vessel, a pretty firmly coherent mass of coke. In the quality of caking there may be every degree from slight fritting or sintering to almost complete fusion. The caking is due to a portion of the constituents of the coal, under the influence of heat, forming coal-tar, which, on becoming charred, cements the non-volatile particles into a solid mass. Some coals lose the property of caking after exposure to the air, and in some cases the caking of a coal depends on the manner in which it is heated, and the degree of heat to which it is subjected.

Caking coal is inapplicable for many furnace operations, in consequence of the caking; as it becomes agglomerated in the furnace into a mass so compact as to be in a greater or less degree impervious to air; in which case the fire, if the fuel was not kept pervious to air by stirring, would soon be extinguished, and stirring in many cases would be quite impracticable. For its employment in such operations, it requires to be previously converted into coke, or mixed with non-caking coal.

Non-caking or free-burning coal does not, in burning, cake or sinter together in any sensible degree; and when heated in close vessels in a state of fine powder, yields a feebly coherent or powdery coke. A fire supplied with coals of this description remains open, the air penetrating freely the burning mass.

Cannel or Parrot Coal.—This is a variety of bituminous coal; it is called cannel, a corruption, it is said, of candle, from its property of burning with a clear flame, like a candle; and parrot (in Scotland) from its property of splintering, or flying off with a loud crackling sound, when flat fragments of it are placed upon the surface of the fire. It does not soil the fingers, is brown or black, and of glistening fracture. There are varieties which are susceptible of a fine polish; common jet, for example, is a variety of cannel coal. This class of coal contains a large quantity of *disposable* hydrogen; it is therefore especially valuable in the manufacture of gas.

Boghead cannel or Torbane mineral is of a dull brown colour; its sp. gr. is about 1·184. It yields on heating about 70 per cent. of volatile matter, and from 18 to 25 per cent. of an *aluminous* ash, usually containing from 6 to 10 per cent. of carbon; the coke or residue retains the form of the coal. This mineral, which formed the subject of the trial already referred to, is very valuable for the manufacture of paraffin, paraffin oils, and gas, on account of the very large percentage of volatile hydrocarbons it yields.

The sp. gr. of bituminous coal varies from 1·2 to 1·5. This variety of coal, fresh from the pit, loses, after its exposure to the air, a portion of its moisture, retaining according to its nature from 1 to 12 per cent.; artificially dried, it reabsorbs moisture from the air. On an average this kind of coal leaves less ash than brown coal or turf, but more than wood.

ANTHRACITE.—This variety is found in the lowest portion of the carboniferous strata. It is much more difficultly combustible than the other kinds of coal; it contains 90 per cent. or more of carbon; it does not sinter in the least degree; it yields but a small portion of volatile matter; it burns almost without flame and with a steady red glow, giving out great heat. Some varieties decrepitate considerably. It is very compact; in powder, as well as in lump, its colour is deep black.

THE GASES CONTAINED (OCCLUDED) IN THE PORES OF COAL.—Coal almost always contains in its pores a variable quantity of gas, the nature and proportion of which differs with the different varieties of coal. The bituminous coals of the South Wales basin contain very little, and that little is almost exclusively carbonic anhydride. Steam coal of South Wales frequently contains a very large quantity of marsh gas, which is evolved to a great extent after it has been raised; it, therefore, not unfrequently happens that the coal in a ship's hold, for example, gives out so large a quantity that the air becomes highly explosive. Cannel coal contains a more complex hydrocarbon, ethane (C_2H_6), than marsh gas. Jet contains hydrocarbons of higher molecular weight than ethane, whereas the gas contained in the pores of anthracitic coal consists almost exclusively of marsh gas. This class of coal yields by far the largest volume of gas: "1 lb. of some anthracites will give off nearly a couple of gallons of gas." The gas in lignite consists almost entirely of carbonic anhydride, mixed with a small quantity of carbonic oxide (CO) and nitrogen.

In a vacuum, especially at a gentle heat, the gas is readily disengaged from the pores of coal.

WEATHERING OF COAL.—By the term "weathering" of coal is meant the change which coal undergoes on exposure to the air. The weathering is due to the absorption of oxygen from the air, which combines with a portion of the carbon and a portion of the hydrogen of the coal; in the one case forming carbonic anhydride and in the other water, whilst another portion of oxygen enters into combination with the coal, or some constituent of it. The state of this combination is unknown. If coal contains iron pyrites, the oxidation of this sulphur compound also takes place.

It is stated by those who have investigated this subject, that the oxidation of coal free, or nearly free, from iron pyrites, is impeded rather than promoted by the presence of moisture in the air; but that the oxidation of pyrites in coal is increased by the presence of moisture. Heat favours the oxidation in both cases.

Very little is known as to the conditions favourable or unfavourable in coal as regards weathering, with the exception that iron pyrites in the coal greatly assists its decay; and when present in considerable quantities may render the coal, owing to the disintegration which occurs from its oxidation, comparatively worthless after the fuel has been exposed for some time to the influence of the air.

SPONTANEOUS IGNITION OF COAL.—Closely connected with the weathering is the spontaneous ignition of coal, which also proceeds from oxidation. When the oxidation of the fuel takes place rapidly, the temperature of the air surrounding the coal becomes, of course, from the generation of heat, increased, and will continue to increase as the oxidation goes on; and as the oxidation is promoted by increase of temperature, so will the oxidation increase with the temperature. The ignition of coal undergoing oxidation is, therefore, very liable to take place unless the heated atmosphere around the coal is continually removed by cooler currents of external air. "The first unequivocal sign of incipient combustion is a peculiar smell, termed 'fire-stink' by the colliers, which appeared to me to be precisely similar to that which is produced by distilling coal at the lowest temperature at which decomposition commences. I came to the conclusion that such incipient decomposition had begun, and conceived that it was due to the heat developed by the oxidation of accumulated finely divided coal, just as in the well-known case of a heap of oiled rags." (*Percy.*) Dr. Percy believed, and Richter's experiments, so far as they have been carried out, confirm the opinion, that coal most liable to spontaneous ignition is not that which contains most iron pyrites; therefore, the spontaneous ignition of coal is due to the heat developed by atmospheric oxidation of the organic substances of coal, and not to that resulting from the oxidation of iron pyrites.*

One of the Inspectors of Mines, Mr. Galloway, has shown that the coal-dust in the atmosphere of a coal mine largely contributes to its explosive character.

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* See Appendix B.

CHAPTER II.

Methods for determining the Heating Power of Fuel. Calorific Power. The mode of calculating the Calorific Power of Fuel from its elementary composition. The unit of Heat. Andrews', Favre and Silberman's, Ure's, and Thompson's Calorimeters. Calorific Intensity: affected by the nature and quantity of the combustion products, &c. The Intensity may be calculated from the elementary composition of the Fuel. Formulæ for the Calculation of the Calorific Intensity. Exercises on the Heating Power of Fuel.

OF the elementary constituents of fuel, *only* the carbon and hydrogen* enter into union with the oxygen of the air, and therefore these are the only elements in the fuel which contribute to the generation of heat; further, if the fuel contains oxygen, this constituent must be considered as if already combined with its equivalent quantity of hydrogen in the fuel. That quantity of hydrogen is therefore considered to be ineffective for the generation of heat, and it is *only* the hydrogen which

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* The constituents of iron pyrites will each enter into union with oxygen, but as this mineral is a foreign, and not a natural, substance of coal, we do not take their union with oxygen into consideration.

is in *excess* of that amount, and which we have already termed *disposable* hydrogen, which is effective.

The meaning of the terms CALORIFIC POWER, or, as it is sometimes called, the absolute heating power, and CALORIFIC INTENSITY, or pyrometric heating power, must now be explained; and how or by what means the calorific power and calorific intensity of fuels are determined.

CALORIFIC POWER.—The *absolute* amount of heat which any substance evolves in burning cannot be ascertained, but the *relative* amounts evolved by *equal weights* of different substances can be accurately determined. This is accomplished by transferring the heat emitted by the combustion to a *third* body, and determining the number of *thermometric degrees* a *given weight* of this third body is raised in temperature by different substances. We thus arrive at the relative amounts of heat they evolve in the act of *combining with oxygen;* the quantity of heat thus estimated is termed the *calorific power* of the substance. The calorific power is not affected by the rapidity or slowness with which the combustion takes place; it remains constant under these varying conditions.

Some of the early experimenters on the calorific power of substances employed ice as the *third body*, and from the amount of ice liquefied, they measured the amount of heat; the apparatus employed, they termed a *calorimeter.* There is an objection to ice, on account of the difficulty of collecting the whole of the water produced by the liquefaction of the ice. Rumford, therefore, substituted water for ice, and although many improvements have since been made on Rumford's method as regards the form of apparatus employed in the experiments, and corrections in the calculation of the results, water is still all but universally employed as the *third body.**

It has been ascertained by experiment, that one part by weight of carbon, when it combines with oxygen sufficient to form the compound carbonic anhydride (CO_2), evolves heat sufficient to raise the temperature of 8080 parts by weight of water 1° Centigrade ; this is usually expressed by saying that the calorific power of carbon is 8080, or that carbon evolves 8080 *units* of *heat* during its conversion into CO_2.

Favre and Silberman found by experiments that one gramme of carbonic oxide (CO), in its conversion into CO_2, evolved 2403 units of heat ; consequently, the *amount* of CO which contains *one gram of carbon* will evolve 5607 units. In the preceding paragraph we have seen that *one gram* of carbon, in its conversion into CO_2, evolves 8080 units ; therefore, *one gram* of carbon, in its conversion

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* Recently Bunsen has re-employed ice as the third body in certain calorific experiments.

into CO, will evolve (8080−5607)2473 units; this is less than one-half the heat it, the CO, evolves in its conversion into CO_2. A probable explanation is, that in the conversion of carbon into carbonic oxide (CO), some of the heat generated by the combination is rendered latent by the passage of the carbon from the solid to the gaseous state. Whatever may be the reason, the student will not fail to observe the great loss of heat and waste of fuel which takes place when the carbon becomes *only* converted into CO and not into CO_2.

It has also been ascertained by experiment that 1 part by weight of hydrogen, when it combines with 8 parts by weight of oxygen, water being produced, evolves heat sufficient to raise the temperature of 34,462 parts by weight of water 1° C.; the calorific power of hydrogen is therefore stated to be 34,462.

With the aid of these data, the calorific power of fuel may be calculated from its *chemical composition;* but before illustrating this by examples, the student must know what *thermal unit* is employed for determining the calorific power of bodies.

Unit of Heat.—The *unit of heat*, or the *thermal unit,* chosen for comparison, is not everywhere the same. In France the one selected is the quantity of heat necessary to raise the temperature either of one kilogramme of water, or one gramme of that liquid, from 0° to 1° C. This latter unit is frequently employed in England, but not universally; 1 lb. of water, from 0° to 1°C. is employed, and sometimes 1 lb. of water, one Fahrenheit degree between the temperatures of 50° and 60° F.

What unit weight of water is selected is immaterial,* although it is most desirable that one standard be universally adopted; but it has hitherto been considered not immaterial what portion of the thermometric scale was selected, as the specific heat of water was considered to increase slightly as the temperature increased beyond its point of greatest density. But Hirn, in recently investigating this subject, has arrived at the conclusion that the specific heat of water does not exhibit any irregularity near its point of maximum density, but merely changes somewhat more quickly below than above that point.

If the elements of a fuel consisted of carbon and hydrogen only, it would only be necessary to *multiply* the weight of each of the elements in *one part* by weight of the fuel by their *respective calorific* values, and add the *products* together.

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* Whatever unit weight for water is adopted, the same unit weight must be adopted for the substance whose calorific power has to be determined; thus, if a kilogramme of water is employed, a kilogramme of the substance whose calorific power is to be determined must also be employed. And the unit of heat, or that quantity of heat which raises the temperature of the unit weight of water 1°, will vary of course according to the thermometric scale employed.

Thus, for the sake of illustration, suppose a fuel contained in 100 parts 85·71 of carbon and 14·29 of hydrogen—

$$0{\cdot}8571 \times 8080 + 0{\cdot}1429 \times 34462 = 11849{\cdot}99$$

One part by weight of this fuel would, therefore, evolve in burning, the carbon being all converted into CO_2—heat sufficient to raise 11849·99 parts by weight of water from 0° to 1° C.

If the fuel contained oxygen as well as carbon and hydrogen, it would be necessary, as previously noticed, to deduct from the total quantity of hydrogen the amount necessary to combine with the oxygen in the substance, and to account, as available for evolving heat, only the remainder of the hydrogen, the *disposable* hydrogen, with the carbon.

For example, a sample of peat has the following percentage composition:—

Carbon	61·53
Hydrogen	5·65
Oxygen	32·82
	100·00*

As oxygen combines with hydrogen in the proportion of 8 to 1, the number representing the amount of oxygen divided by 8 will give the

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* The ash and nitrogen of the peat have been omitted, as they were not material for the purpose of illustration, and it is assumed that all the carbon becomes converted in the burning into CO.

number representing the quantity of hydrogen which will combine with the oxygen; thus, $32{\cdot}82 \div 8 = 4{\cdot}10$: now, $5{\cdot}65 - 4{\cdot}10 = 1{\cdot}55$, the amount of disposable hydrogen; consequently—

$$0{\cdot}6153 \times 8080 + 0{\cdot}0155 \times 34462 = 5471{\cdot}3$$

is the calorific power of the peat. One part by weight of this peat would, therefore, raise 5471·3 parts by weight of water from 0° to 1° C.

The calorific power of various bodies is given in my work, "The Student's Guide in the Higher Branches of Chemistry," and also a description of the apparatus employed by Dr. Andrews in this difficult field of research, together with a reference to the apparatus and methods employed by M. Favre and Silberman in a like investigation.

The apparatus employed by Andrews and that employed by Favre and Silberman would be unsuitable, if correct, for determining the calorific power of fuel for commercial purposes; but I have found they are unsuitable for coal even in the most delicate scientific investigations, as no constant quantity of the products from its combustion can in them be obtained.

The modification proposed by MM. Kestner and Meunier of Favre and Silberman's apparatus for the determination of the heating power of coal will be noticed in Chapter III.; we shall in this only notice the two calorimeters (Ure's and Thompson's) that are suitable, and sufficiently exact, for technical purposes: the latter is to be preferred in most cases.*

Ure's calorimeter in Fig. 1 is founded on the same principle as the one employed by Rumford, but somewhat improved. It consists of a large copper bath (*a*), capable of holding 100 gallons of water. It is traversed four times, backwards and forwards, in four different levels, by a zig-zag horizontal flue or flat pipe (*b*), which is nine inches broad, and one deep, ending in a round pipe at (*c*), which passes through the copper bath, and there receives the top of a small black-lead furnace (*d*); this furnace contains the fuel; the crucible is surrounded, at the distance of one inch, by a second, and this is surrounded by a third, crucible; the stratum of inclosed air between the crucibles serving to prevent the heat from being dissipated. A pipe (*e*), from a double cylinder bellows, enters the ash-pit of the furnace at one side, and supplies a steady but gentle blast, to carry on the combustion, kindled at first by half an ounce of red-hot charcoal. So completely is the heat, which is disengaged by the burning of the fuel, absorbed by the water in the bath, that the gases

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* A method by Berthier is frequently described at considerable length in books. The method consists in estimating the calorific power of coal by the amount of litharge it reduces. I found long ago that this method is perfectly unreliable, and therefore it is useless to describe it.

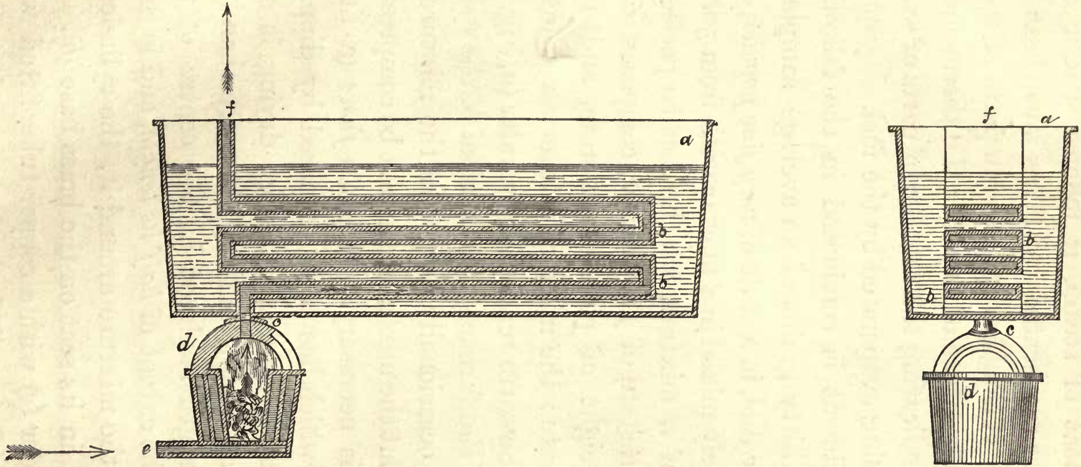
discharged at the exit orifice (*f*), have usually the same temperature as the atmosphere.

The copper bath weighs 2 lbs. per square foot; it is on an average 5½ feet long, 1½ wide, 2 deep, and 1¾ broad. Including the zig-zag tin-plate flue, and a rim of wrought-iron, it weighs altogether 85 lbs. Since the specific heat of copper is to that of water as 94 to 1000 lbs., the specific heat of this vessel is equal to that of 8 lbs. of water, for which, therefore, the proper correction is made by leaving 8 lbs. of water out of the 600 or 1000 lbs. used in each experiment. The heating power of the fuel is measured by the number of degrees of temperature which 600 or 1000 lbs. of water are raised by it; deducting the 8 lbs. from the amount for the specific heat of the copper.

When the object is to determine the latent heat of steam or other vapours, they may be introduced through the top orifice (*f*), the latent heat being deducted from the elevation of temperature of the water in the bath, which is calculated from the liquid discharged into a graduated glass placed under the outlet (C). In this case the furnace is of course removed.

The apparatus devised by Mr. Lewis Thompson, is one for determining the calorific power of coal and other combustibles. The combustible, of whatever nature, is burnt in oxygen evolved from an oxidising mixture. The latent heat of steam is

FIG. I.



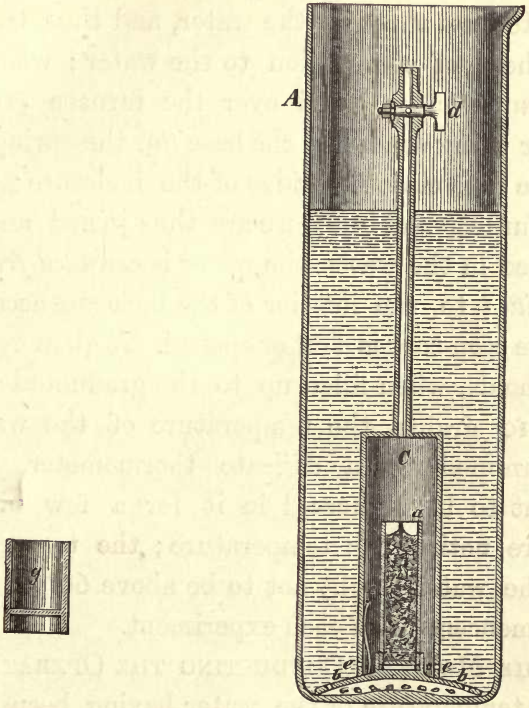
RUMFORD'S CALORIMETER AS IMPROVED BY URE. SCALE ½ AN INCH TO A FOOT.

(*a*) Copper bath capable of holding 100 gallons.
(*b*) Flat tube made of tinned iron for passage of combustion products.
(*c*) End of flat tube fitted to crucible.
(*d*) Black lead crucibles, surrounded by air spaces, for combustion of fuel.
(*e*) Inlet tube for supply of air to fuel.
(*f*) Exit orifice.

taken to be equal to 967° F.; admitting this to be the latent heat of steam, it follows that if 967 parts of water are heated 10° F., as much heat has been evolved as would evaporate ten parts of water having a temperature of 212° F.; the thermometer in this way indicating the number of parts of water capable of being evaporated by the fuel.

The experiment is conducted in the following manner:—Thirty grains of an average sample of coal, or other fuel, in a state of *very fine powder*, are very intimately mixed in a mortar with from 300 to 360 grains of a mixture, which must be perfectly *dry* and in a state of *fine powder*, composed of 3 parts by weight of potassic chlorate, and 1 of potassic nitrate; the mixture is afterwards introduced into the narrower copper cylinder (*a*, Fig. 2), which forms the furnace; the bottom of the cylinder must be occasionally tapped as the mixture is introduced, but the mixture must not be compressed more than is necessary. A *cotton fusee* (a little cotton wick which has been prepared by dipping it in a solution of nitre and then drying it and which acts as a slow match) not more than half an inch in length is placed in the centre of the mixture to the extent of *half its length*, and is fixed by pressing the mixture around it, the cylinder is then placed in its seat on the brass base (*b*). A copper cylinder (*c*) with a copper tube fitted with a stop-cock (*d*) is called the inclosure, it is per-

FIG. 2.



THOMPSON'S APPARATUS FOR DETERMINING THE HEATING POWER OF FUEL.

Scale, 3 Inches to a Foot.

A, Glass cylinder graduated to hold 29,010 grains of water.
(*a*) Furnace in which coal mixture is burned.
(*b*) Base for holding the furnace and inclosure.
(*c*) Inclosure, copper cylinder with tube.
(*d*) Stop-cock for exit of air from interior of inclosure after combustion.
(*e*) Holes in bottom of inclosure for exit of combustion products.
(*f*) Spring (of which there are three) for retaining inclosure on base.
(*g*) Wider furnace for combustion of coke, anthracite, &c.

forated at the bottom with a number of small holes at (*e*) to allow the gases produced by the combustion to pass through the water, and thus transfer the heat of combustion to the water; when the inclosure (*c*) is fitted over the furnace (*a*), the latter being seated on the base (*b*), the springs (*f*) of the base clasp the sides of the inclosure; when the furnace and inclosure are thus joined and immersed in the water, the water is *excluded from*, or *admitted* to, the interior of the inclosure according as the stop-cock is shut or opened. A glass cylinder (*A*) holds, when filled up to the graduated mark, 29,010 grains, the temperature of the water is determined by a delicate thermometer, which ought to be immersed in it for a few minutes before noting the temperature; the temperature of the water ought not to be above 60° F. at the commencement of each experiment.

THE MODE OF CONDUCTING THE OPERATION.—The temperature of the water having been determined and the thermometer withdrawn, and the furnace, containing the mixture and fusee, being seated on the base, the fusee is lighted, the inclosure, the stop-cock being closed, is then fixed over the furnace, and the apparatus is let down to the bottom of the graduated glass cylinder; this part of the operation must be quickly performed so as not to allow the mixture to become ignited before the immersion, otherwise the experiment fails, and the operator's hands and face are in danger of being burnt.

A minute or so after the immersion the wick burns down to the mixture, its combustion then commences, and when it ceases the stop-cock is opened,* and the apparatus (furnace and inclosure) and the thermometer, which must now be reintroduced into the water, are moved gently up and down *in, not out of*, the water, which causes the water within and without the inclosure, and at every *depth*, to acquire the same temperature.

When the thermometer indicates that the temperature of the water has become stationary, that is, that the water at different depths is of a uniform temperature, the temperature is *instantly* noted, and the number of the thermometric degrees to which the water has been heated, represents the quantity of water which would be converted into steam from a temperature of 212° F. If, for example, the temperature of the water has been raised 10° F., we learn that the sample of fuel under examination would be capable of converting ten times its weight of water into steam, since every grain of the fuel has been burnt in the midst of 967 grains of water ; and if the latent heat of

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* Attention should be paid to the state of the exit tube of the inclosure at the conclusion of the combustion. If on opening the stop-cock, air does not freely issue, a pointed wire must be introduced to clear it.

steam be taken at 967° F., then if 967 grains of water be raised 10° F., sufficient heat has been generated to boil off 10 grains of water from 212° F., this then represents the evaporative power of the fuel; and pounds or tons can, of course, be substituted for grains.

As part of the heat generated by the fuel is absorbed by the copper of the apparatus, this amount must be added to every calorific result obtained.* The amount of heat absorbed by the copper is found by multiplying the weight of the copper part of the apparatus by its specific heat, this product gives the weight of water, which, in respect to absorption of heat, would be exactly equivalent to the weight of the copper.

Dr. Percy has found that by inclosing the lower part of the inclosure within a larger metallic cylinder, perforated all over with small holes, so that the escape of the gases from the water was retarded, the experimental results were notably higher; thus, in comparative experiments upon a Welsh steam coal, it was found that its theoretical evaporative power was raised by this addition from 14·41 to 14·96 lbs. of water. The colder the water employed, the smaller will be this loss of heat, owing to the gases being more thoroughly cooled.

In testing coke, anthracite, or other difficultly

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* The amount to be added is generally determined by the maker of the instrument.

combustible substance, the *wider* furnace (g) must be used, and the mixture must be allowed to remain loose and uncompressed in the furnace; but in the case of bituminous coal, &c., the narrower furnace (a) is employed. It is seldom, however, that coke or anthracite is completely burnt, even in the wide furnace, the only plan then is to collect the unburnt particles on a *tared* filter,* and after having washed the particles on the filter free from all soluble salts, the filter and contents must be dried at 212° F., and, when perfectly dry, weighed; the quantity of ash and carbon the unburnt portion contains must then be determined, and from the total quantity of carbon and ash in the fuel employed the carbon in the unburnt portion and the relative quantity of ash must be deducted. We thus arrive at the quantity of the fuel burnt, and hence can determine its evaporative power. The unburnt portion of the carbon and the ash is determined by burning the filter and the coal in a porcelain crucible, previously weighed, until the carbonaceous matter is perfectly consumed. When the crucible is cold, it is again weighed; the weight of the crucible deducted from the weight of the crucible and ash gives the quantity of the latter

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* The filter is first dried in the water or air bath at 212° F., then placed in a stoppered weighing tube, and tube and filter weighed; the same plan is followed when the filter and unburnt portion of the coal has to be dried and weighed, care being taken to employ the same stoppered weighing tube.

substance; this again deducted from the unburnt portion of the fuel gives the carbonaceous matter it contained.

I have found it advisable in burning difficult combustible substances not to let down the apparatus (inclosure, furnace, &c.) to the bottom of the glass vessel at first, but just to let that portion of the *inclosure* surrounding the furnace to dip beneath the surface of the water until the combustion commences, and then to let it down to the bottom.

In determining the heating power of peat by this method, I have found it necessary to mix 15 grains of it with a like weight of a good bituminous coal, the heating power of which has been previously very accurately determined.

After the heating power of coal or other fuel has been determined, the sulphur that was present in the coal may be estimated by precipitating the sulphuric acid, into which it has been converted, by baric chloride, and determining the amount of baric sulphate in the usual manner.

In employing this method for estimating the amount of sulphur in *tar*, it is necessary to add an equal weight of sugar to the tar, otherwise it does not deflagrate satisfactorily.

When wax, spermaceti, and other fusible substances are tested, they require to be in the first place mixed or fused with about three times their weight of manganic oxide (MnO_2) or cupric oxide

(CuO) in fine powder, which serves to regulate the combustion. Sulphur requires no such provision, but may be burned safely with six times its weight of the chlorate mixture.

Dr. Frankland has employed this apparatus for determining the *calorific values of different substances used as food.*

CALORIFIC INTENSITY.—If the heat generated by the combustion be transferred to the *combustion* products, as is the case in the ordinary burning of fuel, the *calorific intensity* or *pyrometrical heating power* of the fuel or other combustible is obtained. The difference between the calorific power and the calorific intensity will perhaps be more clearly perceived if we illustrate the difference by examples. The calorific power carbon is, in its conversion into carbonic anhydride (CO_2), 8080, that is, as we have already explained, the heat generated during the combustion of one part by weight of carbon will raise 8080 parts of water 1° C.; or will heat one part of water from 0° to 8080°C.; or will raise 3·67 parts of water from 0° C. to $\frac{8080}{3 \cdot 67} = 2202°$ C. Now 3·67 parts of CO_2 are produced by the combustion of one part of carbon, and if the heat produced by the combustion be transferred, *not to water*, as is the case in determining the *calorific power*, but to the *product of combustion* (CO_2) as takes place in the burning of fuel or other combustible in pure oxygen, or in air the temperature of the CO_2 would be 2202° C., if its *specific heat were the same as that of water, but this is not the case.* The specific heat of CO_2 is 0·2164, taking water to equal 1·0; the temperature of the CO_2 will consequently be in the inverse ratio,

$$\text{or } \frac{3 \times 8080}{11 \times 0{\cdot}2164} = 10183^\circ \text{ C.},$$

this is the pyrometrical heating power, or calorific intensity of carbon in its conversion into CO_2, when it is burnt in pure oxygen. The student will be aware that 3 parts of carbon combine with 8 parts of oxygen to form 11 parts by weight of CO_2.

The calorific intensity is affected by the *nature* and *quantity* of the combustion products; it is also influenced by the *temperature* of the air or oxygen with which the substance is supplied; by the *amount* of water the substance contains; the *rapidity* with which the combustion is effected—and this will be *modified* by the state of division and porosity of the substance; by the *greater* or *less pressure* under which the combustion takes place.

The calorific intensity of a fuel may be estimated by the pyrometer,* or may be calculated theoretically from its elementary composition. A description of the best form of pyrometer is given in Chapter IV.; the method by calculation will be the one at present described.

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* Thermometers can only be employed to measure temperatures under 600° F. Instruments employed to measure higher temperatures are termed pyrometers.

The calorific intensity of a simple combustible body is obtained by dividing its calorific power by the product of the relative weight of its combustion product into the specific heat of that product.

It has already been shown by calculation what the calorific intensity of carbon is when converted into CO_2, when that element is burnt in pure oxygen. We will now see (1st) what is the calorific intensity of carbonic oxide (CO) when converted into CO_2; and (2nd) the calorific intensity of hydrogen when converted into H_2O, when these substances *are burnt in an atmosphere of pure oxygen.*

1st. The calorific power of CO is, as has been already stated, 2403; its calorific intensity is 7072·9; thus—

$$\frac{2403}{1{\cdot}57 \times 0{\cdot}2164} = 7072{\cdot}9,$$

1·57 being the amount of CO_2 formed by the combustion of one part of CO; and 0·2164 is the specific heat of CO_2.

2nd. In determining the *calorific power* of hydrogen, the compound produced (H_2O) is at first in the state of vapour (steam), but becomes condensed; the heat estimated in the calorimeter is, therefore, the heat of combination including the heat rendered latent in the steam. But in determining the *calorific intensity* of this element the latent heat has to be deducted, because, as the steam does not become condensed in the combustion, as in the calorimeter, its latent heat will therefore not become available, and must, consequently, in calculating the *calorific intensity* of hydrogen, be *deducted* from the calorific power of that element. Now, one part by weight of water (the product of the oxidation of hydrogen) at 100° C., to be transformed into steam of that temperature, must for that conversion absorb or abstract 537~~°~~ Cal of sensible heat, which becomes, and remains, *latent* as long as the water continues in the state of steam.

One part by weight of water at 100° C. requires, as just stated, in order to be converted into steam at 100° C., 537° C.; "a further correction has also to be made for the difference between the specific heat of water (=1) and that of steam (=0·4805) from 0° C. to 100° C., because in the computation of temperature the initial temperature is assumed to be 0° C. This difference is $(1·0-0·4805) \times 100=$ 51·95 thermal units, which must also be subtracted. The sum of these two numbers is $537+51·95=$ 588·95, which is the number of thermal units to be deducted for one part by weight of steam produced; and since for one part by weight of hydrogen nine parts by weight of steam are produced, it is necessary to subtract $588·95 \times 9=5300·55$ from the number representing the calorific power of hydrogen found by experiment in the calorimeter. The number left by subtraction must then be divided by the number obtained by multiplying the weight of steam produced by the specific heat of the steam, in order to ascertain the theoretical maximum temperature resulting from the combustion of hydrogen in pure oxygen," &c.,

$$\frac{34462-5300{\cdot}5}{9\times 0{\cdot}4805}=6743^\circ \text{ C.}$$

Although the calorific power of carbon (8080) is much less than that of hydrogen (34462), yet, as shown by the examples given, its calorific intensity (10183) is much greater than that of hydrogen (6743). The reason of carbon exceeding hydrogen in calorific intensity is due, as will have been observed, to three causes—1st, the specific heat of aqueous vapour is about twice as great as that of CO_2; 2nd, 1 part of hydrogen produces 9 parts of water, whilst one part of carbon produces only 3·67 parts of CO_2; 3rd, the amount of heat in the latent state carried off by the steam.

The *calorific power* of a substance is the same, whether burnt in pure oxygen or in atmospheric air; but the *calorific intensity* is much greater when the substance is burnt in oxygen, than when burnt in air; because the nitrogen, which takes no part in the combustion, absorbs a certain amount of heat, and thus lowers the temperature. The calorific intensity of a simple combustible in air is therefore obtained by dividing its calorific power by the *sum* of the products of the relative weight of its combustion product into its specific heat, and the product of the weight of nitrogen (in the air required for the combustion of the substance) into its specific heat. We find, for example, the calorific intensity of 1 part of carbon in the following way:—For every 1 part by weight of oxygen contained in air, there are 3·35 of nitrogen; now $\overset{32}{8}$ parts of oxygen are required to convert $\overset{12}{3}$ parts of carbon into CO_2; there are associated with the $\overset{32}{8}$ parts of oxygen in the air 26·8 parts of nitrogen, and the specific heat of nitrogen is 0·244. We find the calorific intensity when the carbon is burnt in air to be 2717·6° C.; thus—

$$\frac{\overset{12}{3} \times 8080}{\underset{44}{11} \times 0{\cdot}2164 + 26{\cdot}8 \times 0{\cdot}244} = 2717{\cdot}6^\circ \text{ C.}$$

Paradoxical as it might at first appear, the calorific intensity of carbonic oxide (CO) is greater than that of carbon when burnt in air. It will be seen that it is due to the lesser amount of air the carbonic oxide requires for its combustion; thus—

$$\frac{2403}{1{\cdot}57 \times 0{\cdot}2164 + 1{\cdot}91 \times 0{\cdot}244} = 2982^\circ \text{ C.}$$

In substances containing oxygen it is necessary, as has been before observed, to deduct from the total quantity of hydrogen the quantity necessary to combine with the oxygen in the substance, and to account as available for raising the temperature only the remaining hydrogen, the disposable hydrogen, with the carbon. The quantity of water which is formed by the combustion of the hydrogen by the oxygen in the fuel, as well as that formed by the combustion of the hydrogen by the oxygen of the air, will require to be evaporated, and will, therefore, diminish the available heat.

It is sometimes important to know, not only the calorific power of a given *weight* of any particular fuel, but also the calorific power of a given *volume* of the fuel—say, a cubic foot. This is obtained by multiplying the calorific power of a given weight of the fuel by the weight of a cubic foot.

Formulæ for the Calculation of the "Calorific Intensity," or "Pyrometrical Heating Effect," of Fuel from its Elementary Composition.

Carbon burned *in pure oxygen*—

Let $K =$ Calorific *power* or *absolute heating effect of carbon.*

$c =$ Weight of carbon used (referred to any unit of weight).

$\frac{8}{3}c =$ Weight of oxygen required for the *complete combustion* of c, weight of carbon.

$s =$ *Specific heat* of carbonic anhydride.

$I =$ *Calorific intensity* of the combustion products in degrees Centigrade.

Hence—

(1) $Kc =$ No. of heat units produced by burning carbon.

$$I\left(c+\tfrac{8}{3}c\right)s=\left\{\begin{array}{l}\text{No. of heat units transferred to the}\\ \quad\text{combustion products.}\end{array}\right.$$

$$\therefore I\left(c+\tfrac{8}{3}c\right)s=Kc.$$

$$\therefore I=\frac{Kc}{\frac{11}{3}cs}=\frac{3K}{11s}.$$

Example.—Determine the calorific intensity of one gramme of carbon burned in pure oxygen—

Here $K=8080$ and $s=0{\cdot}2164$.

$$\therefore\ I=\frac{3\times 8080}{11\times 0{\cdot}2164}=10183^{\circ}\text{ C.}$$

Carbon burned *in atmospheric air.*

Since there is contained in the quantity of air required for the complete combustion of the carbon a quantity of nitrogen equal to $8{\cdot}9\dot{3}$ times the weight of the carbon consumed, the calorific intensity will be diminished by the cooling effect of this quantity of nitrogen—

$$8{\cdot}9\dot{3}c=\left\{\begin{array}{l}\text{Nitrogen present in air requisite to con-}\\ \quad\text{vert the C into CO}_2,\end{array}\right.$$

s' = specific heat of *nitrogen.*

Hence—

$$(2)\quad I\left(\tfrac{11}{3}cs.+8{\cdot}9\dot{3}cs'\right)=Kc.$$

$$\therefore I=\frac{Kc}{c\left(\frac{11}{3}s+8{\cdot}9\dot{3}s'\right)}=\frac{3K}{11s+26{\cdot}8s'}.$$

Example.—Determine the calorific intensity of one gramme of carbon burned in air—

$$s'=0{\cdot}2440$$

$$\therefore I=\frac{3\times 8080}{11\times 0{\cdot}2164+26{\cdot}8\times 0{\cdot}2440}=2718^{\circ}\text{ C.}$$

(nearly).

CARBON BURNED *in atmospheric air* (*water* being present).

In this case the absolute heating effect will be further diminished by the quantity of heat which becomes *latent* in the conversion of the water into *steam.* A further correction must also be made on account of the difference between the specific heat of water and that of steam, because in the calculation of temperature the initial temperature is assumed to be 0° C. Thus $(1-0.4805) \times 100$ will be the thermal quantity required to be deducted for this difference of specific heat—

Let $w = \left\{ \text{Weight of water present (unit of weight as before). This also represents the weight of } \textit{steam} \text{ produced.} \right.$

537° C. = *latent heat* of steam.

s'' = *specific heat* of steam.

$(1-s'') \times 100$ = correction for difference of specific heat.

Hence—

$$(3) \quad Kc - \{(1-s'') \times 100 + 537\} \times w = \left\{ \begin{array}{l} \text{No. of heat} \\ \text{units pro-} \\ \text{duced by} \\ \text{the com-} \\ \text{bustion.} \end{array} \right.$$

$$I \left(\tfrac{11}{3}cs + 8.9\dot{3}cs' + ws''\right) = \left\{ \begin{array}{l} \text{No. of heat units trans-} \\ \text{ferred to the com-} \\ \text{bustion products, in-} \\ \text{cluding also steam.} \end{array} \right.$$

$$\therefore I = \frac{Kc - 537w - (1 - s'') \times 100\,w}{c(\frac{11}{3}s + 8.9\dot{3}s') + ws''}$$

Example.—Calculate the absolute heating effect of 4 grammes of carbon in the presence of 1 gramme of water, $s'' = 0.4805$.

$$I = \frac{8080 \times 4 - 537 \times 1 - (1 - 0.4805) \times 100}{4[\frac{11}{3} \times 0.2164 + 8.9\dot{3} \times 0.2440] + 0.4805} = 2563^\circ \text{ C.}$$

Hydrogen burned *in pure oxygen.*

Let h = weight of hydrogen burned.

k = its calorific *power.*

9h = weight of *steam* produced by the combustion of the weight h of hydrogen.

s'' = *specific heat* of steam.

In this case, as the water produced is in the state of vapour, its *latent* heat must be deducted, and also the same correction made for the difference of specific heat.

Hence—

$$(4)\quad I \times 9hs'' = kh - \{0.5195 \times 100 + 537\} \times 9h.$$

$$\therefore I = \frac{h(k - 5300.55)}{9hs''} = \frac{k - 5300.55}{9s''}$$

Example.—Determine the calorific intensity of the combustion of one gramme of hydrogen in pure oxygen.

$$I = \frac{34462 - 5300.55}{9 \times 0.4805} = 6743^\circ \text{ C.}$$

Hydrogen burned *in atmospheric air.*

As one part by weight of oxygen is mixed, in atmospheric air, with 3.35 parts by weight of nitrogen, the weight of nitrogen, mixed with the eight parts by weight of oxygen, required for the conversion of one part by weight of hydrogen into water $= 8 \times 3.35 = 26.8$.

Hence from (4)—

$$(5) \quad I = \frac{k - 5300.55}{9s'' + 26.8s'}$$

Example.—Calculate the calorific intensity of the combustion of one gramme of hydrogen in air—

$$I = \frac{34462 - 5300.55}{9 \times 0.4805 + 26.8 \times 0.2440} = 2684^\circ \text{ C.}$$

Carbon and Hydrogen *burned in pure oxygen.*

From (1) and (4) we have—

$$Kc + h(k - 5300.55) = \left\{ \begin{array}{l} \text{No. of heat units produced} \\ \text{by the burning of the} \\ \text{compound.} \end{array} \right.$$

$$I\left(\tfrac{11}{3}\, cs + 9hs''\right) = \left\{ \begin{array}{l} \text{No. of heat units transferred} \\ \text{to combustion products.} \end{array} \right.$$

Hence—

$$(6) \quad I = \frac{Kc + h(k - 5300.55)}{\frac{11}{3}\, cs + 9hs''}$$

Example.—Calculate the calorific intensity of the combustion of 4 grammes of marsh gas (CH_4) in pure oxygen. Here $c = 3$ grammes and $h = 1$ gramme.

$$\therefore I = \frac{8080 \times 3 + 34462 - 5300.55}{\frac{11}{3} \times 3 \times 0.2164 + 9 \times 0.4805} = 7964^\circ \text{ C.}$$

CARBON AND HYDROGEN, *burned in atmospheric air.*

In this case the number of heat units absorbed by the nitrogen will be expressed from (2) and (5) by

$$I\,(8.9\dot{3}\,cs' + 26.8\,hs')$$

Hence—

$$(7)\quad I = \frac{Kc + h\,(k - 5300.55)}{\frac{11}{3}\,cs + 9hs'' + (8.9\dot{3}\,cs' + 26.8\,hs')}$$

$$= \frac{Kc + h\,(k - 5300.55)}{c\,(\frac{11}{3}\,s + 8.9\dot{3}s') + h\,(26.8s' + 9s'')}$$

EXAMPLE.—Calculate the calorific intensity of the combustion of 4 grammes of marsh gas (CH_4) in atmospheric air.

$$I = \frac{8080 \times 3 + 34462 - 5300.55}{3\,(\frac{11}{3} \times .2164 + 8.9\dot{3} \times .244) + 26.8 \times .244 + 9 \times .4805} = 2699° \text{ C.}$$

CARBON, HYDROGEN, AND OXYGEN BURNED *in atmospheric air.*

The oxygen is assumed not to be present in the substance in a greater ratio than would be requisite to convert the whole of the hydrogen into water; and it may be in less proportion. If h′ be taken to represent the amount of hydrogen which combines with the oxygen present in the fuel, then the amount of hydrogen available for raising the temperature, "the disposable hydrogen," will be denoted by $h - h'$.

Let $D = h - h'$; then formula (7) becomes

$$(8)\quad I = \frac{Kc + \cancel{D}\,(k - 5300.55)}{c\left(\frac{11}{3}\,s + 8.9\dot{3}\,s'\right) + D\left(26.8\,s' + 9\,s''\right) + 9\,h'\,s''}$$

$$\therefore\ I = \frac{Kc + D\,(k - 5300.55)}{c\left(\frac{11}{3}\,s + 8.9\dot{3}\,s'\right) + 26.8\,D\,s' + 9\,h\,s''}$$

Example.—Calculate the calorific intensity of 100 grammes of an anthracite coal of the following percentage composition :—Carbon 94.05, hydrogen 3.38, oxygen 2.57. Here $h' = \frac{2.57}{8} = 0.32$ and therefore $D = 3.38 - 0.32 = 3.06$.

Hence—

$$I = \frac{8080 \times 94.05 + (34462 - 5300.5)\ 3.06}{94.05\left\{\frac{11}{3} \times 0.2164 + 8.9\dot{3} \times 0.2440\right\} + 26.8 \times 3.06 \times 0.2440 + 9 \times 3.38 \times 0.4805} = 2701^\circ\ \text{C}.$$

If a solid body which is unaltered by the combustion be present, as the *ash* in coal, its weight multiplied by its specific heat must be added to the divisor. The quantity of heat lost by the presence of ash in coal is so insignificant that the results are but very slightly affected if the ash be left out of the calculation.

If *ash* be present let x=its weight and δ=its sp. heat ; then (8) becomes—

$$(9)\quad I = \frac{Kc + D\,(k - 5300.55)}{c\left(\frac{11}{3}\,s + 8.9\dot{3}\,s'\right) + 26.8\,D\,s' + 9\,h\,s'' + x\,\delta}$$

Carbonic Oxide burned *in pure oxygen.*

Let T=the calorific power of carbonic oxide (CO).

y=weight of CO burned.

1.57 y weight of CO_2 produced by the combustion of y.

Hence $T\,y$ = No. of heat units produced by the burning of CO.

$I\,(1.57y)\,s$ = No. of heat units transferred to combustion products.

$$(10)\quad \therefore\quad I = \frac{T\,y}{1.57 \times y \times s} = \frac{T}{1.57 \times s}$$

EXAMPLE.—Calculate the calorific intensity of one gramme of CO burned in pure oxygen:— T = 2403.

$$\therefore\ I = \frac{2403}{1.57 \times 0.2164} = 7073^\circ\text{C.}$$

CARBONIC OXIDE BURNED *in atmospheric air.*

One part by weight of CO requires for its conversion into CO_2 0·57 parts by weight of oxygen; there is associated with this amount of oxygen in air 1·91 parts by weight of nitrogen.

Hence—

$$(11)\ I = \frac{T}{1.57\,s + 1.91\,s'}$$

EXAMPLE.—Calculate the calorific intensity of one gramme of CO burned in air.

$$I = \frac{2043}{1.57 \times 0.2164 + 1.91 \times 0.2440} = 2982^\circ\text{ C.}$$

FORMATION OF CARBONIC OXIDE DURING THE BURNING OF FUEL IN AIR.

If in the burning of fuel some of the carbon be converted only into CO, the absolute heating effect will be diminished, because, as has been already noticed, one gramme of carbon in its conversion into CO evolves only 2473 heat units, whereas that weight of carbon in its conversion into CO_2 evolves 8080 heat units.

Suppose in example (8) some of the carbon to be transformed only into CO, the formula becomes as follows :—

Let c° = weight of carbon converted into CO.

$\frac{4}{3}c^\circ$ = weight of oxygen required to convert c° weight of carbon into CO.

s° = specific heat of CO.

K° = the calorific power of the carbon converted into CO.

$4{\cdot}4\dot{6}\ c^\circ = \left\{ \begin{array}{l} \text{weight of nitrogen associated in air with} \\ \frac{4}{3}c^\circ \text{ weight of oxygen.} \end{array} \right.$

Hence—

$$(12)\quad I = \frac{Kc + K^\circ c^\circ + D\,(k - 5300.5)}{c\,(\frac{11}{3}s + 8.9\dot{3}s') + 26.8Ds' + 9hs'' + \frac{7}{3}c^\circ s^\circ + 4.4\dot{6}\,c^\circ s'}$$

EXAMPLE.—Calculate the calorific intensity of 100 grammes of the anthracite coal given in example (8). Supposing only 80 per cent. of the carbon to be converted into CO_2 the remaining 14.05 per cent. being converted into CO. Here $K^\circ = 2473$ and $s^\circ = 0.2479$.

Hence—

$$I = \frac{8080 \times 80 + 2473 \times 14.05 + 3.06(34462 - 5300.55)}{80\,\{\frac{11}{3} \times 0.2164 + 8.9\dot{3} \times 0.2440\} + 26.8 \times 3.06 \times 0.2440 + 9 \times 3.38 \times 0.4805 + \frac{7}{3} \times 14.05 \times 0.2479 + 4.46 \times 14.05 \times 0.2440}$$

$$= 2603^\circ\ C.$$

EXERCISES.

1. Calculate the calorific intensity of ether $(C_2H_5)_2O$ in oxygen gas and in atmospheric air.

2. Calculate the calorific intensity of alcohol, C_2H_5HO in oxygen gas, and in atmospheric air.

3. A caking coal from Northumberland was found to have the following percentage composition :—

Carbon	80.54
Hydrogen	4.76
Oxygen	14.70
	100.00

1.76

Determine from these numbers its calorific intensity in air, assuming that all the carbon is converted into carbonic anhydride.

4. A non-caking coal from South Staffordshire was found to have the following percentage composition :—

Carbon	78.46
Hydrogen	4.96
Oxygen	16.58
	100.00

1.58

Determine its calorific intensity from these numbers, assuming that one-half the carbon is converted into carbonic oxide, and the other half into carbonic anhydride.

5. A cannel coal from Tyneside was found to have the following percentage composition :—

1.48

Carbon	87.86
Hydrogen	7.53
Oxygen	2.53
Nitrogen	2.08
	100.00

Determine its calorific intensity from these numbers, assuming that all the carbon is converted into carbonic anhydride.

6. An anthracite from South Wales was found to have the following percentage composition :—

1.35

Carbon	94.05
Hydrogen	3.38
Oxygen	2.57
	100.00

Determine its calorific intensity from these numbers, assuming that 25 per cent. of the carbon is converted into carbonic oxide and the rest into carbonic anhydride.

7. Determine the pyrometrical heating power of a cubic foot of the coals named in each of the preceding exercises, taking the specific gravity of the coal in Exercise 3 to be 1.26 ; that in Exercises 4 and 5 to be 1.28 ; and that in 6 to be 1.35.

CHAPTER III.

Theoretical Heating Power of Fuel never obtained in Practice. The Calorific Intensity deduced from the Elementary Composition of the Fuel not Accurate. How the Elements are combined and their state of Condensation in Coal not known. Evidence adduced that the Organic Elements are arranged differently in different Coals. The Nitrogen may be a Heat Producer. Gruner's Industrial Classification of Coal.

BEFORE proceeding to show that the method for determining the *theoretical* calorific intensity of coal from its elementary composition by calculation is imperfect, we will allude to the *difference* between the *theoretical* heating power and the *practical results.*

Owing to several causes the *total theoretical* heating power of fuel is never obtained in practice :—1st, the fuel is scarcely ever fully consumed, a part escapes combustion by passing off in the form of combustible gases and smoke, and another part remains mixed up with the ash ; 2nd, there is a loss of heat by radiation and also by conduction, the loss by conduction not only occurs through the materials of the furnace, but also from the gaseous products and excess of air which carry with them a considerable portion of the heat into the chimney and air, and also some of the heat is conducted away by the ash which falls through the grate. In calculating the calorific intensity, *the theoretical amount of air* required for the combustion of the fuel is employed, but this is never obtained *in practice*, it requires, in order to approach theory, the most favourable circumstances—such as properly arranged furnaces, the adjustment of the fuel and of the air supplied to it; this latter requires skill and constant attention on the part of the fireman; a large excess of air is generally allowed to pass through the fire, which carries away a considerable amount of heat, and the loss from this cause is very much greater than is generally supposed; further, if any of the carbon becomes converted only into carbonic oxide (CO), it has been shown by examples already given that a great loss of heat will occur. Another portion of the heat is lost by the water present in, and that formed by the burning of, the fuel. It is for this reason that the practice of charring has been adopted. By the charring the whole of the water the fuel contains and also almost all that would be produced from the hydrogen it contains is expelled; there consequently remains an artificial fuel of higher calorific power than the natural one from which it was derived. The charring is, of course, attended with a loss of carbon in the form of CO_2, of CO, and of hydrocarbons.

The loss of heat in a furnace, due to the admission of a greater amount of air than is necessary for the complete combustion of the fuel, may be illustrated by an example. On page 48 it was found that the calorific intensity of carbon burned in air was 2718° C. when the theoretical amount of air for its combustion was supplied. Taking the formula given for this calculation, we see that the exact weight of air needed for the combustion of c weight of carbon is $(8+26.8)\frac{c}{3}$; then if any excess of air pass through the furnace the formula will be modified thus:—

Let a = specific heat of air.
x = a number expressing the *excess* of air passing through, in terms of the amount theoretically required.

Then the heat carried away by this excess of air is $34.8 \times \frac{c}{3} \times x \times a$; if twice as much air passed through as was needed x would equal 1; if three times as much $x = 2$ and so on.

The formula then becomes:—

$$(13)\quad I = \frac{3\,K}{11s + 26.8s' + 34{\cdot}8xa}$$

EXAMPLE.—Determine the calorific intensity of carbon burned in air when double the amount of air than is necessary for its combustion is supplied. Here $x = 1$ and $a = 0.2377$.

$$\therefore\ I = \frac{3 \times 8080}{11 \times 0.2164 + 26.8 \times 0.2440 + 34.8 \times 0.2377}$$
$$= 1410^\circ \text{ C.}$$

The loss of heat in this case is therefore:—
2718−1410=1308° C. or 48 per cent. of the heat possible to be obtained.

Then, again, high temperatures control both the combination of substances and the continuance of the combination of substances that have already combined; thus, at the temperature of 2500° C. oxygen and hydrogen will not enter into union, and carbonic anhydride is resolved into carbonic oxide and oxygen at about 1000° C.; there is, therefore, a limit to combination (combustion), for it ceases at a *point* which has been laid down by St. Clair Deville at 2500° C., and which has been called by him the point of *dissociation*, and the combustion also does not take place below a certain temperature. It really only takes place between the limits of temperature of about 315° C. and 2500° C.

The time required for the combustion of the fuel, and consequently for the evolution of heat, depends upon its state of division and aggregation, and upon its chemical composition. If the fuel be thrown on the fire in large pieces, it burns slowly, and a large proportion of the heat generated is absorbed. If it be wood that is employed, and instead of being burnt in the form of large logs, it be first divided into shavings, the combustion will be so rapid that a large proportion of the heat will, for all useful purposes, be lost. This arises from the greater facility with which the air comes in contact with it when in the form of shavings. If, however, the fragments are still further reduced in size, the smallness of the particles, and the close contact existing between them, excludes the entrance of the necessary supply of air; and for this reason it is extremely difficult to obtain any available heat, either from saw-dust, or very finely-divided coal. But in determining the value of a fuel, not only must the state of division, but also the state of aggregation be taken into account; thus, particular qualities of charcoal, coke, and anthracite may have the same calorific power, and yet differ remarkably in their manner of burning. "Of the three, charcoal, being very light and porous, ignites most easily, and in a given volume contains the least combustible matter; and accordingly, under the same conditions, it is most quickly consumed. Coke also contains less combustible matter in a given volume, and, except when prepared at high temperatures, is more easily ignited than anthracite.*

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* "It is obvious that, on this account, anthracite is not adapted as a fuel for ordinary steam-boiler furnaces; but by the following simple contrivance it may be advantageously employed in these furnaces. The ash-pit is kept filled with water, and deep fish-bellied bars are used, of which the lowest parts nearly, if they do not actually, touch the water. Steam is necessarily evolved from the surface of the water, and enters the fire-place along with the air which sustains combustion. On passing through the incandescent

The practical effect of these differences in the manner of burning will be well understood by experimenting on the three kinds of fuel in a common casting-furnace about one foot square and from two to three feet deep. If an attempt is made to heat a large crucible in such a furnace by means of anthracite, it will be found that the bottom becomes heated to whiteness before the top is hardly red-hot; whereas, by the use of coke, the temperature is not so excessive at the bottom, but is more equally diffused through the furnace. The effect of anthracite as a fuel is the rapid production of an intense heat confined to a space not extending beyond a few inches above the base."—(*Percy.*)

The imperfections attending the method for determining by calculation the *theoretical* calorific intensity of coal may be classified under two divisions; the second is the most important of the two.

anthracite, it is decomposed, with the formation of the combustible gases, carbonic oxide and hydrogen, which are afterwards burned under the boiler at a distance from the fire, by the admission of a suitable supply of air from without. The decomposition of the steam causes a considerable diminution of temperature within the fire-place, but there is no permanent loss of heat, as, on the subsequent burning of the combustible gases derived from the steam, the heat absorbed in the first instance is again given out and economised; there is, so to speak, only a transference of heat from the fire-place to a distance. The bars do not become sufficiently heated to burn rapidly away. The fire-place should be enclosed above by a fire-brick arch, as no part of the boiler should be unprotected above the solid fuel."—*Dr. Percy's "Metallurgy."*

1st. The calculation is based upon the quantity of carbon and hydrogen the coal contains; the methods we adopt at the present time for estimating the different elementary constituents of coal are imperfect, as will be explained in the chapter on the "analysis of coal;" but although the numbers obtained are not in some cases absolutely correct by reason of our imperfect methods, they are in most cases sufficiently exact for all practical purposes.

2nd. In calculating the calorific intensity, we assume that the calorific power of the carbon and hydrogen, in this *complex chemical* compound, coal, is the same as when these elements are in their *free* or *uncombined state;* it is further assumed, in making the calculation, that the oxygen in the coal is, as though it were, in combination with hydrogen, and therefore, in regard to that portion of the hydrogen in the coal, it is considered to be ineffective as regards the generation of heat.

It has been established by the researches of Favre and Silberman that the calorific power of carbon, like its sp. heat, varies with its density; the calorific power as determined by M. Favre and Silberman, and the sp. heat as determined by M. Regnault for the different forms of carbon, is here given :—

	Calorific Power.		Sp. Heat.
Wood charcoal	8080	...	0.24150
Coke from gas retorts .	8047	...	0.20360
Native graphite . . .	7797	...	0.20187
Graphite from blast furnaces . . .	7762	...	0.19702
Diamond	7770	...	0.11687

We are entirely ignorant as regards the density of carbon as it exists in coal, we cannot, therefore, know its proper calorific value; it is possible that its density is different in different varieties of coal, still less do we know the proper calorific value of the hydrogen in coal; it can scarcely be the same when existing as a constituent of a solid body as when it exists in its *free gaseous* state.

From the experiments made on the calorific power of substances, it is known by experiment that the calorific power of a compound *is in general* less than the calorific power of its elements in their uncombined state; and that whatever may be the calorimetric effect of any *chemical change,* whether it be one of *combination* or one of *decomposition,* the calorimetric effect of the *reverse change* is *equal* and *opposite;* if, for instance, the formation of a chemical compound is attended with an evolution of heat, their separation is attended by the disappearance of an equal quantity of heat; therefore the heat produced by the combustion of such a compound must be less, by the amount absorbed in the separation of its elements, than the combustion of those elements in their uncombined state. It has been further ascertained that the calorific power of isomeric compounds varies like the elements with their density; for example, the calorific power of the hydrocarbons belonging to the olefiant gas series ($C_n H_{2n}$) diminishes as their molecular condensation increases, and for each addition of $C_n H_{2n}$ into the molecule, Favre and Silberman infer, from their experiments, that there is a decrease of 37.5 units.

Berthelot has shown that when carbon and nitrogen unite to form cyanogen, an absorption of heat takes place; an absorption likewise takes place in the formation of the amides, hydrocyanic acid, and other compounds. If the nitrogen in coal is combined with some of the carbon, an absorption of heat would most probably take place when they united; if so, the heat will be evolved on their separation; consequently, the nitrogen compound will be, as well as the carbon and hydrogen, a heat producer.

As we neither know how the elements are combined nor their state of condensation in coal, the results obtained in calculating the calorific intensity from its elementary composition can at best be only approximations to the truth.* That the organic

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* MM. Scherrer-Kestner and Meunier have found by experiment that coals, excluding lignites, give a higher calorific power by the calorimeter than the calorific power deduced by calculation.

elements are differently arranged in different coals appears proved, for it has been ascertained by experiment that different varieties of coal having almost exactly the same percentage composition as regards their organic elements have been found to yield different quantities of coke and to vary considerably in calorific power; and so far as investigations have yet proceeded in this direction, the calorific power, with some few exceptions, increases and diminishes with the amount of coke the coal yields.* This is at least true, M. Gruner observes, for coals properly so-called, but not always for anthracites and lignites; he believes that the proximate analysis furnishes an image more true of the essential properties of coal (calorific power, agglomerating power, and ash) than the ultimate analysis of it; and as the proximate method exacts much less time and experimental ability, is in all cases more preferable in an industrial point of view. As a further illustration that the organic elements are arranged differently in different coals, it may be noticed that caking and non-caking coals may have the same elementary composition; therefore, the property of caking must depend upon the proximate constitution of the coal, and not upon its elementary composition.

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* In a few of the exceptions the coal which yielded the least coke had the highest calorific power, and in some other cases when they yielded the same amount of coke they had different calorific powers.

Gruner* divides coals, excluding lignites, into five classes. Although the characters of each class are different, it will be seen from the Table we give that the passage from one class to another is, as is the case in most natural classifications, gradual. The percentage amounts of the organic constituents, as shown by the Table, are comprised between the following numbers :—

Carbon	75 to 93
Hydrogen	4 to 6
Oxygen, including nitrogen	3 to 19

As regards the nature and appearance of the coke, the extreme types, 1st and 5th classes, approximate most closely, but they differ widely, as regards the quantity they yield of it, and volatile matter, and of their inflaming powers. The 1st class yields from 55 to 60 per cent. of coke, and from 40 to 45 of volatile matter, they inflame readily, and burn with a long smoky flame ; the 5th class yields from 82 to 93 per cent. of coke, and from 10 to 18 per cent. of volatile matter, they inflame with difficulty, and burn with a short flame of feeble durability, and almost without smoke.

The combustibility and length of flame depends upon the amount of the volatile matter the coal yields ; but these properties also depend to some

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* "Pouvoir Calorifique et Classification des Houilles." Par M. L. Gruner, Ann. des Mines, 1873, iv. 169. I have availed myself of some of the valuable matter in this Paper.—R. G.

extent upon the quality and quantity of the ash. We see by the Table that the coke commences becoming compact when the carbon reaches 80 per cent., and the oxygen and nitrogen fall below 15 per cent., and these proportions serve as the boundary between *dry* and *fat* coal. As the oxygen diminishes, the coal becomes more friable, less sonorous, blacker, and less dense. The brightness and agglomerating power increases with the amount of hydrogen. These different properties are notably modified by the inorganic substances; the density and hardness increases with the amount of ash, but the brightness diminishes with its increase.

The coals of the 1st class are hard, compact, and sonorous to blows; their colour is rarely pure black, and in all cases their powder is brown. The coals of the 2nd class are in general hard and compact, but in a less degree than those of the 1st class, but they are more brilliant in colour and of a deeper black; they also yield a less proportion of gas, but it possesses a greater illuminating power. The coals of this class are employed in the manufacture of gas, and where a short, vivid, and rapid fire is required, not a moderate, uniform, and sustained heat. The coals of the 3rd class are black, of vivid brilliancy, a little hard, the structure more or less platy; they burn with a shorter and less smoky flame than those of the 1st and 2nd class. By reason of their fusion and agglomeration into a compact mass in the fire they are rendered eminently suitable for the forge. The coals of the 4th class are almost always friable, they inflame with difficulty, and burn slowly with a short and very little smoky flame; they yield of all classes the best coke, but they require to be carbonised immediately on being brought up from the pits. The coals of the 5th class are black and are habitually furrowed with striæ ; it is difficult to burn them in the grate, and, from the small quantity of volatile matter they yield, they are not suitable for the generation of steam and other purposes where a different heat is required, but are well adapted for purposes where a localised temperature is required.

In the Table the ash and water have been deducted, and the coals are made to consist consequently of carbon, hydrogen, and oxygen *only;* this is done in order to compare the calorimetric and experimental heating powers of coal having nearly the same *proportion* of the organic constituents, but which varied in the quantity of ash and water.

The real calorific power was determined by the calorimeter, the evaporative power by the amount of water evaporated in practical operations.* The numbers given with respect to the heating powers,

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* The Table gives the amount of water at 0° C. vaporised at 112° C. per kilogramme of the pure coal burnt.

Gruner's Classification of Coals (exclusive of Lignites) as regards their Industrial Value.

Names of the five Types, or Classes.	Real Calorific Power.	Evaporative Power.	Percentage Composition of the Organic Constituents.			Number of parts by weight of Oxygen—taking the weight of H = 1. *	Weight of Coke yielded by 100 parts of pure Coal.	Weight of Volatile Matters yielded by 100 parts of Coal.	Nature and Appearance of the Coke.
			Carbon.	Hydrogen.	Oxygen.*				
1st *Class.*—Dry Coals, burning with a long flame.	8000 to 8500	6^{k}·70 to 7·50	75 to 80	4·5 to 5·5	15 to 19·5	3 to 4	55 to 60	45 to 40	Pulverulent, or at the most fritted.
2nd *Class.*—Fat Coals, burning with a long flame, or Gas Coals.	8500 to 8800	7^{k}·60 to 8·30	80 to 85	5 to 5·8	10 to 14·2	2 to 3	60 to 68	40 to 32	Caked, but porous, and very brittle.
3rd *Class.*—Fat Coals, properly so-called, or Furnace Coals.	8800 to 9300	8^{k}·40 to 9·20	84 to 89	5 to 5·5	5·5 to 11	1 to 2	68 to 74	32 to 26	Caked, moderately compact, and more or less swollen.
4th *Class.*—Fat Coals, burning with a short flame, or Coking Coals.	9300 to 9600	9^{k}·20 to 10·	88 to 91	4·5 to 5·5	5.5 to 6·5	1	74 to 82	26 to 18	Caked, very compact, but little friable.
5th *Class.*—Lean (Maigre) Coals, or Anthracites.	9200 to 9500	9^{k}· to 9·50	90 to 93	4 to 4·5	3 to 5.5	1	82 to 90	18 to 10	Somewhat slightly fritted, but more frequently pulverulent.

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* This amount includes the nitrogen which Gruner states rarely exceeds 1 per cent. of the organic constituents; but this is rather under the average amount.

and the amount of coke and volatile matter yielded; and the percentage composition of the organic constituents are calculated upon the *pure* coal—that is, coal free from ash and moisture; the experiments and analyses were made with coal in the ordinary state, but from the results obtained it was calculated what the results would have been if the coal had been pure; this was done in order to compare coals having organic constituents in similar proportion.

It may be as well to state that the Table is a union of the results given by Gruner in two Tables.

It has been made evident in this chapter that it would be most desirable for practical, as well as for scientific, purposes that a process should be devised for determining with *minute* exactness the calorific power of coal, so that by the results obtained by this method of examination, and those derived by the exact analysis, &c., the state of condensation of the carbon in every coal, and the proximate composition of the coal, could be arrived at.

An investigation with this important object in view I commenced some time ago, aided by my friend and former student, Mr. C. C. Hutchinson, but for the present we have been compelled to abandon it. We tried the apparatus employed by Kestner and Meunier with a like object in view, but we found that it gave results that were not of that degree of exactness required for such an investigation. The apparatus (Fig. 3) is a modification of Favre and Silberman's, and it is described here, as it may be the means of inducing others to take up this most important investigation.

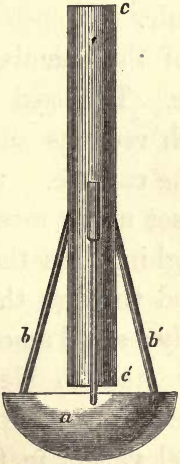
The following is an outline of the description Kestner and Meunier give for the method of using it. They state that they found it expedient after many trials:—

1. Not to use more than half a gramme of coal.

2. For certain coals to employ 60 parts of oxygen and 40 parts of nitrogen, instead of pure oxygen.

3. To give sufficient velocity to the current of gas to maintain vivid combustion.

FIG. 3.



(*a*) Cup or basket of platinum containing the powdered coal.
(*b b*′) Platinum wires suspending the basket.
(*c c*′) Tube conveying the current of oxygen.

4. Lastly, to replace the basket or cartridge

employed by Favre and Silberman by another apparatus which allows of burning a powdered body, and of weighing without loss the ashes produced. These conditions have been realised, they state, thanks to the use of a very delicate thermometer and of a platinum apparatus (Fig. 3).

It consists of a platinum capsule *a* and three wires *b*, *b*, *b* of the same metal, with a tube *c*, *c*, whose lower end opens in the centre of the circumference formed by the rim of the capsule. The upper end of the tube fits in the nozzle of an oxygen blow-pipe which passes through the stopper of the combustion chamber, so that the gas on arriving at *c* flows to the centre of the combustible mass contained in the capsule.

All the joints of the chamber were luted with melted caoutchouc. The coal for determination and the ash which remains after combustion are each weighed in the capsule.

Combustion is set up by means of a particle of wood charcoal weighing less than a milligramme, which is introduced through the opening for the blow-pipe. As only a small amount of coal was employed, a thermometer so delicate had to be employed that the errors of observation were infinitesimal. The elevation in temperature of the water of the calorimeter did not in general exceed one degree of the ordinary thermometer.

As a strong current of gas had to be employed they found that the absorption of the carbonic anhydride was not sufficiently complete without employing a number of Liebig's potash bulbs; they avoided this inconvenience by using soda lime, in place of potash, which absorbs CO_2 very rapidly.

They did not succeed in completely burning the carbon. After each operation the bottom and sides of the capsule remained coated with a layer of that body. This observation shows that it was not completely successful in the hands of the inventors.

CHAPTER IV.

Pyrometers, the Principles on which they have been Constructed. Description and Illustration of Siemens' Electric Resistance Pyrometer.

MANY forms of pyrometers have been invented, but few of them are satisfactory in their indications. We shall, therefore, simply state the principles upon which they have been constructed, describing only in detail the one which is the most perfect.

The principles involved in the construction of the various forms of this heat-measurer may be classified thus :—

1. Change in the volume of bodies.
2. Change in the chemical or molecular state.
3. Transformation of energy.
4. Transmission of energy.

To the first class belong those instruments in which the change of volume of a body, solid or gaseous, is made the subject of observation ; the expansion or contraction following some connected law and being a function of the temperature.

The pyrometers of Daniell and of Wedgewood are illustrations of this method; in the former the *expansion* of a bar of platinum is the indicating agent; in the latter, the *contraction* of a block of fire-clay.

To the second class belong those forms of the instrument which depend upon chemical or molecular changes.

Regnault devised a gas or hydrogen pyrometer for measuring the variable temperatures of furnaces, but since the discoveries of Graham and Deville that iron is permeable to hydrogen at a red heat, the apparatus is regarded as inaccurate.* Lamy invented one in which he employed the decomposition of calcic carbonate and the increase of pressure of the liberated carbonic anhydride in a closed vessel as the indicator. The pyrometer invented by Siemens, and which is illustrated and described further on, is an example of a change in the molecular state of a body.

The third class comprises those instruments in which the energy of heat is converted into an electric current; which is measured. The instrument, the thermopile, is placed either in the furnace itself, exposed to radiation, or its face is placed in contact with some good conducting body.

The fourth class embraces those instruments in which advantage is taken of some agent for the transmission of heat from the *source* to some form of thermometer. This is accomplished either by a bar

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* Ann. Ch. Phys. [3] lxiii. 42.

of metal, one end of which is placed in the furnace, and to the other end is attached an accurate thermometer; or else the heat passes through an orifice in a screen and is concentrated by a lens upon the bulb of a thermometer at a given distance from the source of heat. Another modification is to employ an infusible body of known weight and specific heat. It is placed in the furnace and subsequently removed to a calorimeter, containing a known weight of water; this process is exactly similar to the determination of specific heat by the method of mixtures.

SIEMENS' ELECTRIC PYROMETER, which we shall now describe, "is the only kind which is serviceable, and can be recommended."—(*Weinhold.*)

The principles involved in the construction of this instrument, and its application to the measurement of temperatures, are :—

1st. The increase in resistance to the passage of an electric current through a conductor when that conductor is heated.

2nd. That if two circuits or conductors be offered for the passage of an electric current, the amount of current passing through each branch is inversely proportional to the resistance offered in each separately. From numerous experimental researches Siemens has deduced a law which he believes expresses the functional relations which exist between the increase of resistance and the increment of temperature in a given conductor. This law he expresses by the accompanying formula :—

Let R = the resistance of the circuit,
T = the temperature, computed from the absolute zero, or from $-272°.85$ C.
$\alpha\ \beta\ \gamma$ = coefficients which vary for each metal.

Then $$R = \alpha\sqrt{T} + \beta T + \gamma.$$

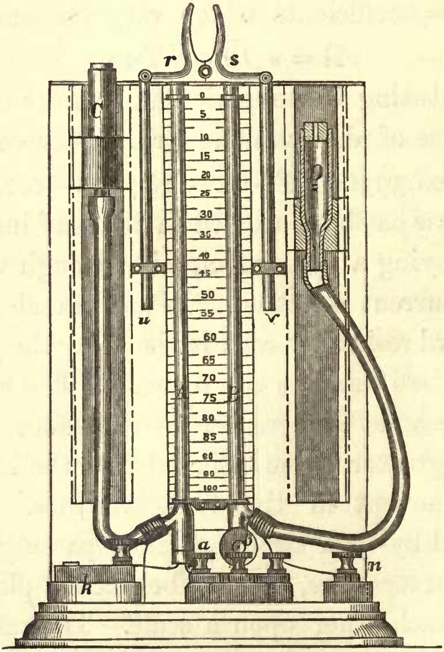
Substituting the experimental values of α, β, γ in the case of platinum the formula becomes—

$$R = 0.039369\sqrt{T} + 0.00216407\,T - 0.24127.$$

This law has been applied in Siemens' instrument by employing a divided circuit through which an electric current is passed. In one branch is placed a standard resistance coil; in the other the platinum spiral to be heated in the furnace. The hotter the spiral becomes the greater its resistance becomes, and the greater is the ratio between the intensities of the current in the two branches. This is measured by each circuit current passing through a voltameter tube, both tubes being placed side by side each other upon a scale. The ratio of the amounts of water decomposed in each gives the relative resistances in each circuit; hence the resistance of the platinum coil is obtained, and by comparing this with its known resistance at 0° C. and by the use of the formula given above the temperature of the furnace is obtained.

The instrument consists of two distinct parts, the voltameter for measuring the current, and its connections, shown in Figs. 4 and 5, and the wrought iron tube, &c., shown in Fig. 6. The current from the battery enters at the binding screw (*a*); when

Fig. 4.

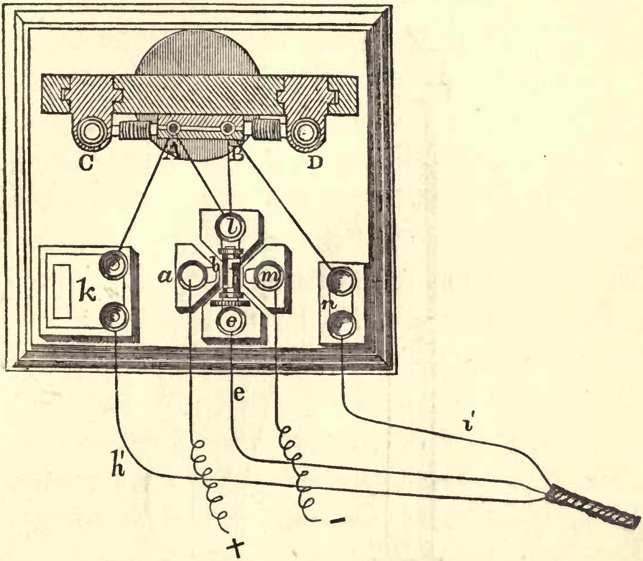


Elevation.

Siemens' Pyrometer.—Voltameter and Connections.
Scale 1½ Inches to a Foot.

the commutator (*b*) closes the circuit, the current passes along the wire (*e*) through the cable and the central insulated wire (*f*) in the heating tube E,

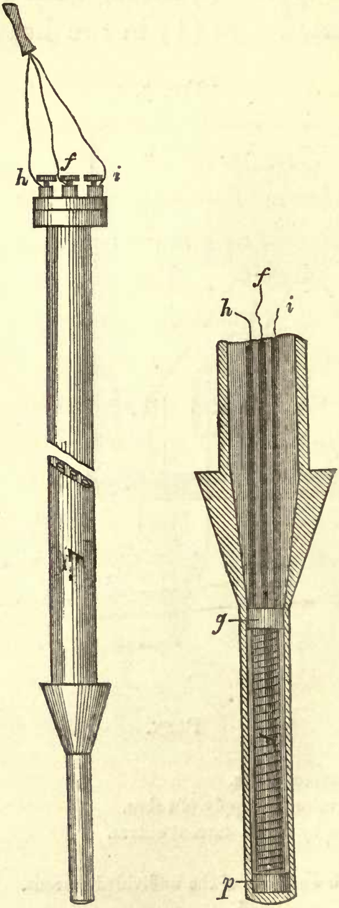
Fig. 5.



Plan.

(A and B) Voltameter tubes.
(C and D) Reservoirs for supply of tubes.
(*a*) Binding screw by which current enters.
(*b*) Commutator.
(*e*) Binding screw and wire of the undivided current.
(*k*) Standard resistance coil.
(*l*) (*m*) and (*n*) Binding screws for return current.
(*h'*) and (*i'*) Wires leading through cable to insulated wires in the heating tube.
(*r*) and (*s*) Weighted levers for pressing rubber pads on the end of voltameters.
(*u*) and (*v*) Weights for end of levers.

FIG. 6.



SIEMENS' PYROMETER—TUBE CONTAINING PLATINUM RESISTANCE COIL.
SCALE 1½ INCHES TO A FOOT.

E, Wrought iron tube.
F Porcelain cylinder upon which is wound a platinum spiral.
f h, i, Platinum wires insulated in pipe-clay.

Fig. 6. The enlarged section shows the platinum spiral wound upon a cylinder of porcelain F; on arriving at the point (g) two passages are open to the current; one to return through the wire (h), into which it is short circuited without passing through the spiral, *back along* the continuation of (h) in the cable through the *standard resistance coil* (k) and from there by the wires shown, through the voltameter tube A, thence to the binding screws (l) and (m) back to the battery. The second passage open to the current at the point (g) is to pass through the platinum coil to the insulated wire (i), which joins the extreme end of the coil at (p), along the cable to the binding screws (n) and hence through the voltameter B and back to the battery as in the case of A.

The two voltameter tubes are closed at their upper end by india-rubber pads kept down by the levers (r and s), which have weights (u and v) at their ends. At their lower ends they are connected by pieces of flexible rubber tubing with the reservoirs (C, D), which slide in vertical grooves, so that the gas generated in each tube can be brought to the atmospheric pressure by adjusting the water level in the reservoirs to the same height as that in the tubes.

The instrument is used as follows:—The end of the wrought iron tube is plunged into the furnace as soon as it has attained the maximum temperature, the commutator is turned to complete the battery circuit. The current passes through the circuit as just described and some of the acidulated water in each voltameter is decomposed. As soon as one of them is about half-filled with gas, the current is stopped and the gas in each tube is brought to the atmospheric pressure by adjusting the reservoirs C and D and the volume of gas in each is read.

The voltameter may be made ready for the next experiment by raising the reservoirs and then pressing the upper part of the weighted levers (*r* and *s*) together; this allows the column of water in the flexible tube to force the gas out by raising the pads. When the tubes are completely refilled and all the gas expelled the levers are allowed to drop. During the experiment the commutator is employed to reverse the direction of the current about every half-minute, in order to avoid the polarization of the voltameter electrodes.

The wires attached to the voltameter are of stout copper, but in the interior of the wrought iron tube platinum wires are substituted for them on account of the high temperature to which they are submitted.

A Table is supplied with each instrument to facilitate the conversion of the readings into temperatures.

CHAPTER V.

Siemens' Regenerative Gas Furnace. Its Advantages. The Gas Producer. The Construction and Working of the Producer. The Construction and Working of the Furnace.

It has already been shown that in ordinary furnaces there is a great loss of heat and waste of fuel, consequently many inventors have endeavoured in a variety of ways to burn fuel more economically in manufacturing operations. The most philosophical and successful of these inventions is the furnace devised by Mr. C. W. Siemens. The defects of ordinary furnaces, which have been already noticed, are greatly obviated in Mr. Siemens' furnace, and therefore a greater amount of the heating-power of fuel is utilised. In addition to this a class of fuel, such as slack, breeze, peat, sawdust, &c., which could not be advantageously burned in an ordinary furnace, can be economically employed in that of Siemens'.

The advantages are briefly effected as follows:—1st, by transforming the fuel used into gaseous products; 2nd, by mixing the gases thus produced with, as near as is practicably possible, the amount of air requisite for their complete combustion; 3rd, by burning the gaseous fuel directly in contact with the substance to be operated upon by the heat; and, 4th, by the heat of the combustion products, which in the ordinary process of burning is wasted, being stored up and utilised to raise the temperature of the gaseous fuel before it is burned in the combustion-chamber. This utilisation of the heat of the combustion products constitutes the process of "regeneration,"—that is, the retransference of the waste heat of the combustion products to the hearth of the furnace.

The description of the furnace will be divided into two parts:—1st, the Gas Producer; and, 2nd, the Furnace proper, with the Regenerators.

GAS PRODUCER.—Fig. 7 represents one of these producers for the transformation of a solid into a gaseous fuel. It consists of a rectangular chamber built of fire-brick, and usually placed below the level of the ground; one side of this (*b*) is inclined at an angle of 45° to 60°. The lower part of this sloping side consists of an iron grate (*c*), with horizontal bars, for the admission of air to the incandescent fuel; the lower side of the furnace is formed by the fire-bars (*d*). By means of the water-pipe (*e*) a limited quantity of water is

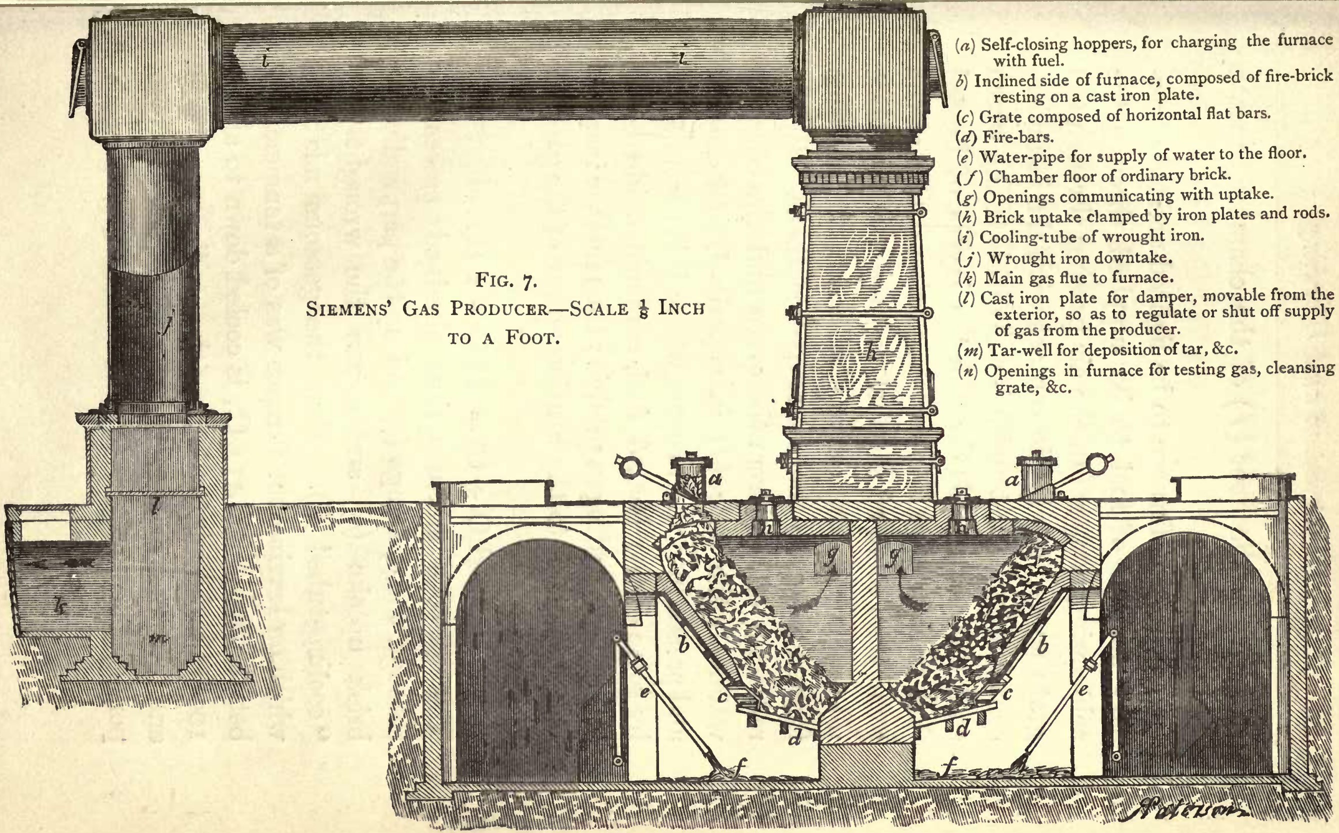


FIG. 7.
SIEMENS' GAS PRODUCER—SCALE ⅛ INCH TO A FOOT.

(*a*) Self-closing hoppers, for charging the furnace with fuel.
(*b*) Inclined side of furnace, composed of fire-brick resting on a cast iron plate.
(*c*) Grate composed of horizontal flat bars.
(*d*) Fire-bars.
(*e*) Water-pipe for supply of water to the floor.
(*f*) Chamber floor of ordinary brick.
(*g*) Openings communicating with uptake.
(*h*) Brick uptake clamped by iron plates and rods.
(*i*) Cooling-tube of wrought iron.
(*j*) Wrought iron downtake.
(*k*) Main gas flue to furnace.
(*l*) Cast iron plate for damper, movable from the exterior, so as to regulate or shut off supply of gas from the producer.
(*m*) Tar-well for deposition of tar, &c.
(*n*) Openings in furnace for testing gas, cleansing grate, &c.

supplied to the floor (*f*) of the chamber beneath the fire-bars.

Suppose the furnace to be lighted and the necessary amount of fuel to be supplied through the self-closing hopper (*a*), the air passing through the grate (*c*) and coming in contact with the incandescent fuel forms first carbonic anhydride (CO_2), which as it passes upwards through the layers of heated fuel is converted into carbonic oxide (CO); at the same time some of the fuel resting on the incline (*b*) undergoes destructive distillation, there is thus formed a certain amount of hydrocarbons. By the radiation of heat from the grate and fire-bars the water on the floor (*f*) is vaporised, and ascends and passes into the furnace where it is decomposed by some of the heated fuel, carbonic oxide being formed and hydrogen set free; thus further increasing and adding to the heating power of the gaseous fuel, thus—

$$2\,H_2O + C_2 = 2\,CO + 2\,H_2.$$

The gaseous mixture thus obtained passes up through the openings (*g*) and up the perpendicular brick uptake (*h*), and enters the wrought iron "cooling-tube" (*i*). Here the gaseous mixture, which on leaving the furnace was of a temperature between 300° and 430° C., is cooled down to about 100° C.; the mixture, from the cooling, contracts and becomes denser, thereby establishing a preponderating weight to the descending gaseous matter in the wrought iron downtake (*j*), which forces the current of gas forward through the main flue on to the furnace.

A slight excess of pressure over the atmosphere is also produced, which exercises the following beneficial effects:—1st, the gaseous mixture passes into the furnace with a slight outward pressure; 2nd, any leakage of air into the main gas flue is thereby prevented; the leakage would be injurious, as it would be attended with the formation of explosive mixtures. From the downtake the gaseous fuel proceeds into the brick flue (*k*) which leads to the Regenerative Furnace. The movable iron plate (*l*) acts as a damper for the greater or less communication of this *block of gas producers* with the main flue, *several sets of producers* being frequently used, in connection with *one flue*, so as to afford a constant and steady supply of gas.

The tarry matter produced is deposited in the tar-well (*m*) during the passage of the gaseous mixture to the main flue. The openings (*n*) in the arched roof of the producer, and which are fitted with covers and stoppers, are for the purpose of testing the gas by allowing it to escape and then igniting it; and also for the introduction of iron bars necessary for the removal of the clinkers, &c., formed in the furnace.

The following is the percentage composition of the gas from the producers according to analyses made at St. Gobain :*—

Hydrogen . .	from	4 to 11	per cent.
Carbonic oxide	„	15 to 19	„ „
Carbonic anhydride . .	„	6 to 7	„ „
Nitrogen . .	„	75 to 63	„ „

The hoppers (*a*) are kept continuously filled with fuel, and are covered with an iron plate so as to prevent the escape of gas on introducing fresh fuel into the body of the producer.

When the producer is constructed to utilise *very* small coal, or poor fuel, the water-pipe (*e*) is replaced by a steam blast, by which means a mixture of air and steam is blown into the producer. According to the capacity, each furnace converts from one to three tons of fuel into gas per day.

REGENERATIVE REHEATING FURNACE.—The special application of the Regenerative Gas Furnace we shall describe, is that form of it employed for reheating iron or steel.

The furnace consists of three parts—the VALVES, the REGENERATORS, and the HEATING CHAMBER. Fig. 9 is a longitudinal section through the body of the furnace showing the REGENERATORS and HEATING CHAMBER. In Fig. 8

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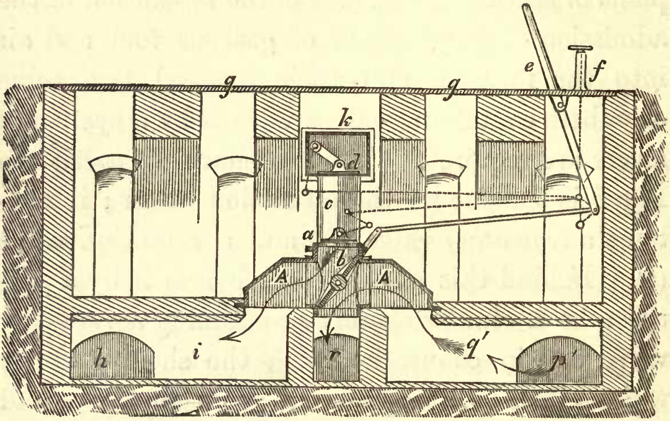
* Orsat's apparatus described in the next Chapter affords a ready means of determining the amount of CO and CO_2 in the gaseous fuel.

is shown a section of the valve arrangement by a plane parallel to, and situated in front of, the plane of section of Fig. 9. For the regulation of the admission of the currents of gaseous fuel and air into the furnace, and their reversal, two valve chambers containing valves worked by a system of levers are required. The one shown in section in Fig. 8 is the one for the admission of air; it contains a *regulating* valve (*a*) and a *reversing* valve (*b*). Behind this and separated from it by a partition is a similar chamber containing a *reversing* valve, and in connection with the short tube (*c*) which communicates with the main flue, the end being closed by a *regulating* valve (*d*). The reversing valves (*b*) are worked by two independent levers, one of which is shown at (*e*), with the rods and levers in connection with it. The regulating valves (*a*) and (*d*) are worked by two independent screw standards, one of which is shown at (*f*). To avoid confusion in the drawing this system of rods and levers has been indicated by dotted lines only. The construction and working is as follows:—The pit in which the valve-chambers are placed is covered in with iron plating (*g*), in which are openings for the admission of air; the air thus entering passes through the valve (*a*), and takes the direction to the left indicated by the arrow into the flue (*h*). The gas entering from the main flue into the oblong iron tube (*k*) passes

Fig. 8.



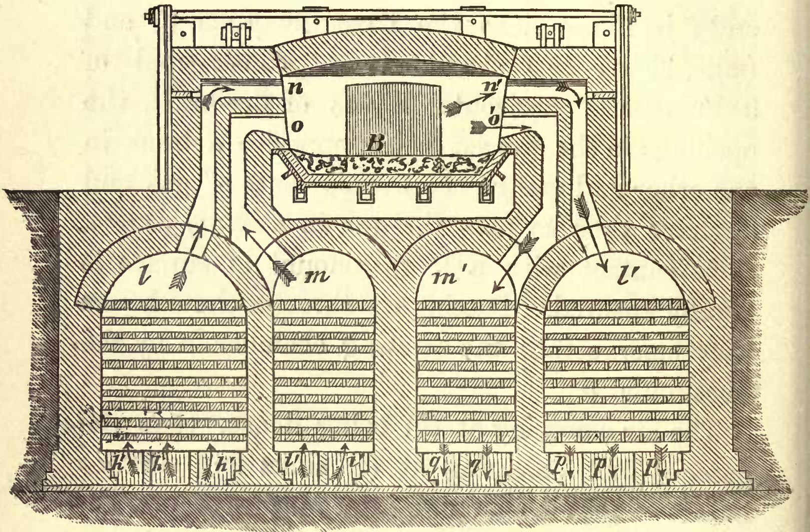
Siemens' Reheating Furnace—Section, showing Valves and Flues.
Scale ½ Inch to a Foot.

(*A*) The valve-chamber made of cast iron.
(*a*) Air regulating valve.
(*b*) Air reversing valve.
(*c*) Short iron tube through which the gaseous products pass into the gas valve-chamber similar to A, and containing gas reversing valve like (*b*).
(*d*) Gas regulating valve.
(*e*) Hand lever for reversing the air valve (*b*), another behind this similarly connected for reversing the gas valve.
(*f*) Screw standard connected as shown by dotted lines for working the regulating valve (*a*), another behind it working the regulating valve (*d*).
(*g*) Iron plating for cover of pit.
(*h*) Air flue leading to regenerator.
(*i*) Partition behind which is gas flue to regenerators.
(*k*) Square tube communicating with main gas flue.
(*p′*) Flue communicating with chamber (*l′*).
(*q′*) Partition behind which is a flue communicating with chamber (*m′*).
r) Exit flue leading to chimney stack.

through its regulating valve (*d*), the short pipe (*c*), its own valve-chamber, and emerges into a flue behind the brick partition (*i*), separating it from the air flue. Passing along their respective flues, the air and gas ascend from their continuations *h′* and *i′* in Fig. 9 into the REGENERATORS (*l*) and (*m*). These two chambers are constructed of a number of horizontal layers of fire-brick, the openings in the one set being opposite a brick in the other and *vice versâ;* the currents of gas and air have thus to pass through in a *zigzag* course, their contact with a large amount of surface is hereby ensured. Passing up through these layers they emerge into the heating chamber B by the flues *n* and *a*.

The air emerging at (*n*) being denser than the gaseous fuel emerging at (*o*) sinks and diffuses into it so that a thorough intermixture occurs. On being kindled at these openings the mixture burns with a moderate calorific intensity, the flame passing directly over the hearth of the chamber B. The products of combustion pass away to the right through (*n′*) and (*o′*) into the Regenerator (*l′*) and (*m′*), here they pass over the large cooling surface of brick divisions and are deprived by the brick surface of a large amount of heat, consequently they emerge into the flues (*p*) and (*q*) at a much lower temperature than on leaving the hearth of the furnace. Entering (*p′*) and the flue behind

FIG. 9.



SIEMENS' REHEATING FURNACE—LONGITUDINAL SECTION.
SCALE ⅛ INCH TO A FOOT.

(*h′*) Continuation of flue (*h*) in Fig. (8).
(*i′*) Continuation of flue behind (*i*) in Fig. (8).
(*l*) and (*m*) Regenerating chambers.
(*n*) and (*o*) Entrance flues for the air and gas.
B The heating chamber.
(*n′*) and (*o′*) Flues similar to (*n*) and (*o*).
(*l′*) and (*m′*) Regenerating chambers.
(*p*) Flue in connection with (*p′*).
(*q*) Flue in connection with that behind partition (*q′*).

(*q′*); Fig. 8, they pass through the valve-chambers, in the direction indicated, into the central flue (*r*); this flue is in communication with a high chimney stack, as in an ordinary furnace.

After the furnace has been in action sometime the fire-brick divisions in (*l′*) and (*m′*) by abstracting heat from the combustion products passing through them are raised to a high temperature. When this has been attained, which is generally in about half an hour, the valve (*b*) and the one in the chamber behind it are reversed from *right* to *left*, establishing the currents of air and gas in the opposite direction to the original one. They pass up respectively through the heated chambers (*l′*) and (*m′*), and by coming in contact with the heated surfaces have imparted to them the heat of which the combustion products had been deprived. Emerging on to the bed of the furnace on the opposite side of the hearth they are burned at (*n′*) and (*o′*); there is now superadded to the heat of combination the heat derived from the heated regenerators, as the air and combustible gases have carried back to the furnace the larger portion of the heat carried away by the former combustion products. The chambers (*l*) and (*m*) now act as the cooling surfaces, and absorb heat from the escaping products which will be conveyed back to the hearth on the next reversal of the circulation. The chambers (*l*) and (*m*) and (*l′*) and (*m′*) therefore alternately *abstract* and *restore* heat.

In practice, a period of about half an hour occurs between each reversal. The carbonaceous matter (smoke) which is seen proceeding more or less from the stack of an ordinary furnace is almost entirely absent in these furnaces. By regulating the proportion of air and gas burned, the intensity and nature of the flame can be varied, just as we can vary the flame in an ordinary Herepath blow-pipe ; it can be made either reducing, oxidising, or neutral, the working being under the entire control of the workman.

The temperature attainable is much higher than that of an ordinary furnace, because the heat is constantly accumulating. This accumulation is, however, limited in two directions, by the fusibility of the materials employed in the construction of the furnace, and the interference by *disassociation;* for if the temperature exceeds a certain degree, decomposition of the combustion products takes place, which is attended with an absorption of heat, and the combination of the oxygen of the air with the elements of the fuel is counteracted.

" The economy of this form of furnace is proved by the fact that a ton of iron can be heated to the welding point with 7 cwt. of coal ; and a ton of steel melted with 12 cwt., whilst from two to three tons of coke were formerly employed to produce the same effect."—(*Siemens.*)

The use of this kind of furnace daily increases. It has not only been applied to the manufacture of iron and steel, but to a variety of chemical industries, as the manufacture of glass, pottery, &c.

We will conclude the description of these furnaces with a summary of some of the many advantages Mr. Siemens claims for them:—

a. The employment of inferior descriptions of fuel, such as slack, coke-dust, lignite, peat, &c., together with a saving on the quantity made use of to the amount of from 40 to 50 per cent.

b. A daily increase of the work done in a furnace of given dimensions amounting to at least 30 per cent., which is a result of the almost unlimited calorific power at command, even when only a moderate chimney-draught is available.

c. Perfect uniformity of heat throughout the furnace and greater durability of the brickwork, owing to the absence of ashes, by which the fusibility of the surfaces with which they come in contact is increased.

d. The production of a flame of such purity as greatly to diminish waste by oxidation or deterioration of the metals operated on.

e. Great cleanliness and saving of space in works, since the gas producers are invariably erected outside the works.

f. Increased command of the heat employed and of the chemical effects produced by the flame, which can be immediately checked when required, or at once changed from an oxidising to a reducing one, or *vice versâ.*

g. Absence of smoke from the chimney-stack which in the neighbourhood of large towns, and in some other situations, is of great importance.

CHAPTER VI.

Technical Examination and Analysis of Coal. Orsat's Gas Apparatus, its Description and Use.

Friability.—The amount of loss which coal suffers in transport depends upon its friability. This may be approximately ascertained by placing in a barrel 1 cwt. of the coal in lumps of nearly uniform size, each lump weighing about 1 lb. The barrel is made to rotate horizontally, and after fifty rapid revolutions have been given, the contents are riddled and the powdered coal weighed; the friability can thus be expressed in percentages.

Length of Flame, &c.—"For the purpose of observing the behaviour of coal on combustion, an unweighed quantity is heated in a muffle with admission of air. In this operation care must be taken to observe whether the fuel ignites *easily* or with *difficulty;* whether it *cakes* or *disintegrates;* whether it burns with a *long* or *short* flame; whether the flame is *intense, smoky, more* or *less bright, steady,* or *vacillating*, and whether a *smell* is generated; whether the resulting coke continues weight of a body

equal vol. of water.

to burn for a *long time* or *easily goes out;* and whether the remaining ash is easily crumbled friable or not."

THE SPECIFIC GRAVITY.—Care must be taken in determining the specific gravity to select a piece of coal as homogeneous as possible. The specific gravity is determined in the usual way, the sample is suspended from the scale-pan by a piece of horsehair and weighed first in air, then in water; care being taken before it is weighed in water to free it from all adhering air bubbles.

A piece of coal, however homogeneous it may appear to the eye, is really not so: it yields in different parts different amounts of ash, combustible matter, &c.; therefore, in determining the quantity of ash, coke, sulphur, &c., a lump of the coal—say 1 lb. in weight—ought to be powdered, and an average sample of the powder taken for the different determinations.

In making the quantitative determinations of the moisture, &c., in coal, it is necessary to make the determinations in the state or condition in which the coal is delivered to the analyst. It is therefore advisable, since powdered coal on exposure to air always loses appreciably in weight, to pulverise the sample as soon as received, and then immediately to weigh out for each of the different quantitative operations.

MOISTURE.—For the estimation of the moisture the coal requires to be in fine powder, and weighed between two watch-glasses clasped together by the ordinary Bunsen's clasp. Coal, like most other substances, is usually dried at 212° F. (100° C.), but more correct results would probably be obtained by drying it at 221° F. (105° C.). The coal ought to be weighed after being in the drying-bath *one hour*, as it gains in weight if kept in the bath beyond that time, the *increase* in weight being due probably to the absorption of oxygen. As moisture requires heat for its evaporation, it is not only injurious by increasing the bulk of the fuel, but by abstracting a quantity of heat; two determinations ought to be made so as to obtain correct results. About 30 grains (2 grams) of the coal may be employed for each determination; and if it is desirable to ascertain its hygroscopic qualities, the dried sample of coal should be left exposed to the air for 24 hours and then re-weighed.

It has been stated in describing the properties of lignite in Chap. I. that that class of coal contains, in comparison with true coal, a large amount of water; but other tests have been proposed and employed to distinguish lignites from true coal. One method consists in subjecting the coal to dry distillation and examining the aqueous distillate for *acetic acid*. The distillate of brown coal contains a considerable quantity of that acid, whilst that obtained from other coals does not contain it.

Another method, and the best, is to heat as much of the pulverised specimen as can be held on the end of a spatula with about 80 grains of a solution of caustic potash (sp. gr. 1·12) for several minutes; if the solution becomes dark-brown or opaque the coal is a lignite, but if it remains colourless, or has only become slightly-yellowish, it is a true coal.

ASH.—About 30 grains of the coal in powder is weighed in a porcelain or platinum crucible; the crucible, the lid being removed, is ignited over a gas, or other lamp, until the whole of the combustible matter is consumed, which, of course, is indicated by the ash ceasing to have a black or greyish hue. The crucible, when cold, is weighed, and the percentage of ash calculated. We have already noticed in Chapter I. that the *quantity* and *quality* of the ash influences the quality and suitability of the coal for many industrial purposes.

SULPHUR.—Sulphur may exist in coal, as we have noticed, in two states, in the state of sulphate and in the state of sulphide in iron pyrites. The total amount in both states is generally determined by mixing *intimately* about 20 grains of the coal in very *fine* powder with from 140 to 160 grains of potassic nitrate, 320 grains of sodic chloride, and 80 grains of potassic carbonate. These substances must be *dry*, and in *fine* powder, and *free* from sulphates. The mixture is placed in a platinum crucible, and gently heated, until the ignition of the mixture has ceased; the heat is then increased until the mixture fuses, and is kept in that state until the fused mass is white.* The light is then removed, and the crucible, when cold, is placed in a beaker with about 12 ounces of boiling water, and subsequently hydrochloric acid is slowly added until the solution is decidedly acid; the solution ought then to be heated up to near the boiling point and kept at that temperature for some time, so as to expel as large a quantity of the oxides of nitrogen as possible; baric chloride is then added, and after the mixture has stood for some hours the precipitated baric sulphate is collected on a filter, washed, dried, ignited, and weighed in the usual manner; the amount of sulphur is then calculated.

As the sulphur existing as sulphate does not injure the quality of iron when the fuel is used in the smelting of that metal, whilst the sulphur in iron pyrites greatly deteriorates its industrial value, not only in iron smelting, but when employed for steam purposes, the late Dr. Grace Calvert proposed a method for estimating the quantity of sulphur existing as sulphate, and that existing in combination with iron, forming iron pyrites. For

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* Some analysts first ignite the crucible, then add in small quantities at a time the mixture of flux and coal; after each addition the lid of the crucible must be immediately replaced; and when the deflagration ceases a fresh quantity of the mixture is to be introduced.

this purpose about 60 grains of the coal in very fine powder is weighed; it is then boiled for several hours in water containing about the same quantity by weight of pure sodic carbonate; afterwards the solution is filtered, and the insoluble portion rapidly washed with boiling water; the filtrate is acidulated with hydrochloric acid, baric chloride being subsequently added. Some hours after the precipitation has taken place, the baric sulphate is collected on a filter, washed, dried, ignited, and weighed, and the amount of sulphur calculated in the usual way.

The residue insoluble in the sodic carbonate solution is, after being dried at 212° F., fused with the mixture of sodic carbonate and potassic nitrate, and the process carried on as directed in the first paragraph on the estimation of sulphur.

In order to distinguish between the sulphur in the two states in coke, nitric acid must be added in excess to the filtered sodic carbonate solution, and the solution then heated to near the boiling point for some time before the baric chloride is added. The rest of the operation is conducted in the way described with regard to coal.

VOLATILE MATTER AND COKE.—The following is the method I adopt for the determination of volatile matter and coke:—About 500 grains of the coal in fragments of about the size of a nut is placed in a porcelain crucible, which is afterwards covered with the lid and placed in a Hessian crucible, the bottom of which is covered with small fragments of powdered charcoal; and after the introduction of the porcelain one, the space between the sides of the two crucibles is packed with similar fragments of charcoal, and finally the top of the inner crucible is covered over in like manner. The outer crucible is covered with a lid and placed in an assay-furnace, where it is heated up to full redness and kept at that temperature for about one hour. When the crucibles are quite cold, the inner one is taken out, and, after it has been freed from any adhering dust, is weighed; the loss in weight is due to the expulsion of volatile matter including moisture, the residue consists of non-volatile matter, coke and ash. If the moisture is determined in the coal, it may be deducted from the total amount of the volatile matter; and if the ash is determined in the coke it may be deducted from the weight of that substance. If the coal contains iron pyrites, part of its sulphur is volatilised, but from a quarter to a half remains behind in combination with the iron.

Other analysts adopt the following method:—About 30 grains of the undried coal in *powder* is weighed in a platinum crucible; it is afterwards heated to bright redness over a Bunsen's burner for 3½ minutes, and then immediately, without allowing it to cool, for the same length of time over a blast gas-lamp, and kept at a *white heat;* it is afterwards, when cold, weighed. Either of these methods will inform the analyst whether it is a caking or non-caking coal.

VALUING GAS COALS.—A method by the late Dr. Richardson is given in some analytical books for valuing this class of coal; but I think the process is open to the same objection as the one proposed by Bunsen and Playfair with a somewhat similar object; the objection I make to it is, that for the quantity of coal employed, there is too large a heating surface; consequently, neither the quality nor the quantity of the gas will correspond with that obtained on the manufacturing scale.

For valuing gas coal properly for commercial purposes the apparatus manufactured by Mr. Sugg, the gas engineer, ought to be employed; it consists of the following parts:—

1. A retort of cast-iron of a D shape, 18 inches long from mouth-piece to the back, 5 inches in diameter, and 5 inches high; the charge of coal is 2·24 lbs., or the $\frac{1}{1000}$th part of a ton. The mouth-piece of the retort has a rising pipe attached, 20 feet in length.

The condenser is of the ordinary form, and consists of 1-inch wrought-iron pipes of an aggregate length of about 80 feet arranged vertically, and attached to a number of separate boxes. Each of these boxes is provided with a stop-cock. These are opened when all the gas has passed into the gas holder, and the tar and other products that have been condensed are collected in an appropriate vessel and their amounts ascertained.

The apparatus is provided with two square purifiers provided with water joints, they are adapted to receive any purifying agent the experimentalist may wish to employ. Provision is made for collecting specimens of the unpurified gas.

A 10-feet gas-holder is in general large enough in experimenting upon $\frac{1}{1000}$th part of a ton of ordinary coal; but cannel coal requires one of larger size. To obviate the inconvenience attending the use of a larger holder two metres of the form devised by Mr. Mann are employed; by this means one-half the gas passing from the retort will be led away to a float of four or more lights, while the outlet from the lower metre leads directly to the gas-holder. The lower metre is provided with an index from which the quantity of gas passed through it is ascertained; this amount doubled, gives the total number of cubic feet produced.

The gas-holder is furnished with a cycloid and counterbalance weights, so that during the carbonization of the coal, and the consequent passage of gas to the holder, by a proper adjustment of the weights, all unnecessary pressure may be taken off the retort; a pipe leads from the holder to the photometer to determine, if required, the illuminating power of the gas.

First heat the retort to the proper temperature, open all the cocks and fill the gas-holder tank with clean water to such a height as will just cover the crown of the gas-holder, so that when it is slightly raised from the bottom of the tank the surface of the water and the edge of the crown may be exactly even; the index will then point to zero. If a metre is employed, it must also be supplied with water and adjusted to the proper line. The purifiers are next charged with the purifying material; one reason for employing two purifiers is to enable the operator to employ two different kinds of material, and another reason is, to enable one to ascertain whether the coal under examination requires a greater or less purification.

Having procured a fair sample of coal, about 1 cwt. is pounded and passed through a coarse sieve; and from the sieved portion, after it has been well mixed, 2·24 lbs. are weighed and placed in a scoop. All the cocks, excepting those which interfere with the direct passage of the gas from the retort to condenser, purifiers, and gas-holder, are now to be closed. The scoop and contents should then be placed in the retort, the lid of which, previously luted with clay or lime, being at once secured as quickly as possible. As soon as the lid is secured, a sufficient number of counter-balance weights should be added to the gas-holder, so as to take off all pressure upon the retort, or so as to produce "a level gauge."

When the charge is worked off, which is ascertained when the gas-holder ceases to rise, the inlet-cock to the holder is shut off and the quantity of the gas in the holder observed by the scale attached. The quantity of condensed products and of *coke* is also ascertained.

Before attempting to make the quantitative experiment as described, it is necessary to expel the air from all the different parts of the apparatus; for this purpose the retort should be first charged with half the quantity of coal, and the gas produced allowed to blow through and drive out the air.

If the experimenter has not Sugg's apparatus, he will find that the method I adopt for the estimation of volatile and non-volatile matter, and which has been previously described, will give the amounts of these two forms of matter in nearly the same quantities as those obtained in practice. The following analyses of gas coals were made in this manner by Mr. James Dunne, the manager of the Kingstown Gas Works, whilst an evening student with me in the year 1864:—

I. BOGHEAD CANNEL COAL.

Specific gravity . . .	1·184

Proximate Composition.

Water	1·55
Volatile matter . . .	62·09
Fixed carbon (coke) . .	18·20
Ash	18·16
	100·00
Amount of sulphur in the coke	0·133
,, ,, in the volatile matter . . .	0·616
	0·749
Percentage of nitrogen . .	0·84

II. MICKLEY COAL (NEWCASTLE).

Specific gravity . . .	1·26

Proximate Composition.

Water	0·59
Volatile matter . . .	35·86
Fixed carbon (coke) . .	61·42
Ash	2·13
	100·00
Amount of sulphur in the coke	0·314
,, ,, in the volatile matter . . .	0·352
	0·666
Percentage of nitrogen . .	1·48

III. NEWCASTLE PELTON MAIN.

Specific gravity . . .	1·243

Proximate Composition.

Water	0·89
Volatile matter . . .	29·87
Fixed carbon (coke) . .	68·77
Ash	0·47
	100·00

Amount of sulphur in the coke	0·615
,, ,, in the volatile matter . . .	0·976
	1·591
Percentage of nitrogen .	1·77

IV. CARLISLE COAL.

Specific gravity	1·273

Proximate Composition.

Water	0·76
Volatile matter . . .	35·97
Fixed carbon (coke) . .	57·11
Ash	6·16
	100·00

Amount of sulphur in the coke	2·288
,, ,, in the volatile matter . . .	3·026
	5·314
Percentage of nitrogen .	0·43

V. WIGAN CANNEL COAL.

Specific gravity . . .	1·284

Proximate Composition.

Water	0·82
Volatile matter . . .	36·09
Fixed carbon (coke) . .	61·02
Ash	2·07
	100·00

Amount of sulphur in the coke	0·639
,, ,, in the volatile matter . . .	0·543
	1·182
Percentage of nitrogen .	1·42

The Carlisle is, what is termed by gas manufacturers, a *dirty* coal ; the gas produced from it will require, on account of the large quantity of sulphur compounds it must contain, the largest quantity of purifying material to remove them. The Newcastle Pelton Main will yield a larger amount of nitrogenous compounds than the other four coals. The Boghead Coal, from the larger amount of volatile matter it yields than the other four, will yield the largest amount of gas.

HEATING POWER.—The determination of the heating power has been described in Chapter II.

ULTIMATE ANALYSIS OF COAL.—For the determination of the elementary organic constituents in coal the student is referred to works on quantitative analysis like that of Fresenius for the processes to be adopted; we will merely remark that only 3 grains of anthracite, and from 5 to 7 grains of bituminous coal ought to be employed; more correct results are obtained by employing these quantities than larger amounts. The nitrogen is determined by Will and Varrentrapp's method; about 15 grains of the coal should be employed for this latter estimation.

Errors in the Ultimate Analysis of Coal.

"When coal contains much inorganic matter, especially iron pyrites, the usual method of calculating its composition from the data obtained in the process of organic analysis may be erroneous in a sensible degree. The ashes left by incineration are estimated as inorganic matter, and the proportion of *oxygen* is found by subtracting the sum of the carbon, hydrogen, nitrogen, and ashes, from the amount of the dry coal subject to analysis. By incineration, the iron of the pyrites is converted into ferric oxide, and the sulphur, in a greater or less degree, into sulphuric anhydride (SO_3), which may remain in combination with any bases in the ashes—such as lime—capable of forming a sulphate *not decomposable* at a red heat. Supposing the whole of the sulphur of the sulphide to be retained in this state in the ashes, for one part by weight of iron pyrites there would be an increase of one part by weight due to oxygen *derived* from the air during incineration. The whole amount of this error, provided no correction be made, would fall upon the oxygen. It is not asserted that the whole of the sulphur is oxidised, or that the whole quantity of the oxidised portion is retained as a sulphate in the ashes, but that a considerable portion of a stable sulphate may be produced during incineration will appear from analyses of coal and coal ashes.

"It is certain that the alumina in the ashes must, either wholly, or in great measure, exist in combination with silica as clay; and clay holds water in combination *which cannot be expelled* except at a temperature far more than sufficient to decompose coal. Hence, during the process of the organic analysis of the coal, the water in the clay will be expelled, and so occasion an error of excess in the determination of the hydrogen. This source of error has been pointed out by Regnault.

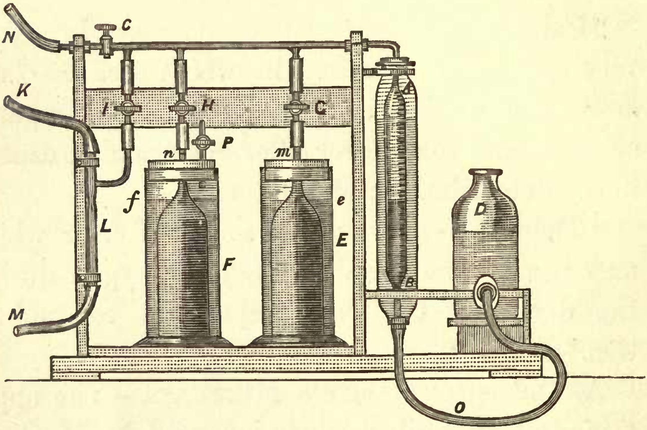
"Calcic carbonate is sometimes present in coal in very appreciable quantity, in which case carbonic anhydride would be evolved during the organic analysis, and so an error of excess would be caused in the determination of the carbon.

"There is, lastly, another source of error which may result from the absorption of oxygen during the drying of the coal preparatory to combustion."—(*Percy.*)

ANALYSIS OF GASEOUS MIXTURES.—The apparatus to be described is one invented by M. Orsat of Paris. It is adapted for a rapid and sufficiently accurate estimation for industrial purposes of furnace gases—namely, carbonic oxide, carbonic anhydride, oxygen, and nitrogen.

The apparatus consists of a cylinder, A B, drawn down at both ends, and open to receive a graduated tube of such size that every division will represent half a cubic millimetre. The space between the two is filled with water, in order to have the tube, and consequently the gas, which is being analysed, at a constant temperature, and thus avoid corrections for dilatation. This graduated tube communicates at A, with a horizontal capillary tube provided near its extremity with a stop-cock

Fig. 10.



ORSAT'S APPARATUS FOR THE ANALYSIS OF FURNACE GASES.

A B graduated tube for measuring the gas.
C stop-cock for admission of gas.
D aspirating bottle.
E absorbing cylinder containing potash.
F " " " ammonia and copper solution.
e and *f* marks to show the height of solution.
G stop-cock for potash cylinder.
H " " " copper solution cylinder.
I stop-cock for expulsion of gas.
K tube for admission of water to tromp.
L water tromp.
M exit tube of tromp.
m and *n* zero marks of cylinders.
N admission tube for gas.
O flexible rubber tube, joining graduated tube and aspirator.
P stop-cock for admission of air into cylinder F.

C, through which the gases to be analysed are introduced into the apparatus. At B it is connected by means of an india-rubber tube O, with an opening near the bottom of the bottle D, which serves to produce a current of gas into the graduated tube when it is lowered, and forces the gas out of it when it is raised. The capillary tube A C is connected by two branches H and G, each of which has its own stop-cock, with two bell jars placed in cylinders E and F, which contain the *absorbent liquids.*

The cylinder E is filled up to the mark *c* with a solution of caustic potash of 1·357 sp. gr. In the bell glass a bundle of tubes open at both ends are placed. When the gas enters that vessel the pressure forces part of the liquid into the cylinder, uncovering the tubes wet with the potash solution, thus presenting to the gas such an amount of surface contact that the absorption is almost instantaneous.

A bent tube in the cork provides for the necessary admission of air. In order that all the joints may be perfectly air-tight, the corks, E, F, A, B, are covered with sheet india-rubber, or corks of that material are employed.

The bell jar in cylinder F contains a roll of copper wire gauze, which must be slightly conical in shape and reach to the top of the jar. An ammoniacal solution composed of two-thirds by volume of a cold saturated solution of ammonic chloride and one-third of commercial ammonia is introduced into F. The solution is colourless when prepared, but soon becomes blue in contact with the copper. As it absorbs oxygen very rapidly the communication with the air is effected by means of a stop-cock, P, which must only remain open while the cylinder F is in use.

The liquids in the cylinders must have free access to the bell jars.

The tubes *m* and *n* must almost touch the stop-cocks, and the rubber connections must be made tight by binding them with two or three turns of copper wire and twisting the ends together.

The aspirator D is filled (all the stop-cocks being opened) with water, acidulated with 5 or 6 c. c. of hydrochloric acid until, it resting on its support, the liquid stands in the graduated tube at 100. The object of the acid is to overcome the tension of the ammoniacal vapours, and to neutralise the alkalies when by accident they enter the capillary tubes.

How to Use the Apparatus.—Before commencing the analysis of any gaseous mixture, the apparatus must be freed from air or other gaseous matter it may contain. This is accomplished by successively filling the graduated tube with gas and afterwards expelling it through the stop-cock I. This process is conducted in the following manner: The cock C is shut and I opened, the aspirator D is then raised till the liquid is just on the point of entering the capillary tube; I is then shut and C opened and D lowered; the gas to be examined passes into the apparatus and fills the graduated tube. This volume of the gas is then expelled as before by closing C and opening I and raising D. When this has been done two or three times the apparatus may be considered to be practically free from all *foreign* gaseous matter.

If the tube conveying the gas to the apparatus be of extreme length to effectually free the instrument of gas in the manner described would be a lengthy operation, and, therefore, to save time and labour it is better to use the tromp L. To do this a funnel is attached to the extremity of the tube K, and placed under a small stream of water, which need only be a few centimetres in height. The water runs into the tube L, and is discharged at M, and in its passage produces a strong aspiration. By keeping C and I open the gas may be rapidly drawn out of the apparatus. It requires about one and a half litres of water to draw out a litre of gas, the quantity varying a little according to the height of the fall of water.

The next thing to be done is to bring the absorbent liquids to the zero marks *m* and *n* in the respective vessels; this must, of course, be done for each vessel separately. All the cocks but G having been closed, the aspirator D must be slowly lowered; the potash solution in E will rise, and when it reaches zero, *m*, the connection tube O must be nipped firmly between the finger and thumb so as to completely close it; as D is replaced on the stand, G is at the same time closed. The stopcocks H and F are next opened, all the others remaining closed, and the absorbent liquid in F is brought to the zero mark *n* as in E, and when D is replaced on the stand H and F are shut.

Some practice and caution are required in order to guard against passing the zero point, and thus forcing the absorbents into the capillary tube.

The sample of gas to be analysed is now taken; for this purpose the cock I is opened, all the others being shut, D is then slowly raised until the water in the graduated tube stands at the zero point; I is then closed, D replaced on the stand and C gradually opened; the liquid in the graduated tube comes to equilibrium at 100, the tube having become filled with the gas; C is then closed. Should the pressure exceed or be lower than that of the atmosphere, it is advisable in the first instance to take a little more than 100 c. c., and after a few minutes to partially open I, so as to establish an equilibrium and bring the volume to 100 c. c., when this is done I is *shut;* and G is opened and D raised till the liquid stands very nearly at the zero point in the measuring tube; the gas has now been forced into the bell jar containing the potash solution; by alternately raising and lowering D, a perfect exposure of all the gaseous particles to, and renewal of, the absorbing fluid is effected. The raising and lowering should be repeated at least three times, and oftener when the solutions have been for some time in use. The last time the gas is to be passed into E, the liquid in the graduated tube must be brought exactly to the zero point; D is lowered, and the stop-cock G quickly closed, so that the liquid in the bell jar stands *exactly* at the zero point *m*. If D be now placed alongside of the tube A B in such a way that the liquid in it and the measuring tube are brought to precisely the same level, the gas is under its original, atmospheric, pressure, and we ascertain the diminution it has undergone. This diminution represents the volume of those gases present in the original gaseous mixture which have been absorbed by the potash; in furnace gases this will be due to carbonic anhydride (CO_2). If sulphurous anhydride (SO_2), sulphuretted hydrogen, and chlorine be present, they will also be absorbed. Sulphurous anhydride can be determined in the presence of carbonic anhydride by employing a solution of potassic bichromate in sulphuric acid, or a solution of potassic permanganate, as an absorbent prior to passing the gaseous matter into the potash solution.

After the estimation of the CO_2, the gas is passed into the vessel F, all the free oxygen and carbonic oxide are absorbed by its solution; the operation is carried on, and the amount absorbed ascertained, exactly as described with regard to E.

The quantity of gas unabsorbed will be the amount of nitrogen present in the gas.

Generally speaking the two gases, oxygen and carbonic oxide, do not exist in furnace gases in the presence of each other; but if they do occur together, their relative proportions can be determined by a simple calculation.

If it should be thought necessary to directly determine the amounts of each of these two gases, it may be accomplished by employing a third cylinder containing either pyrogallate of potash or sticks of phosphorus for the absorption of the oxygen, prior to absorbing the carbonic oxide by the ammonia copper solution. As before stated, the respective amounts of each, when they are both absorbed in the same solution, can be readily calculated if the air has been the only source of the oxygen.

The clue for this calculation is furnished by the relation existing between the amount of nitrogen and that of the other products. In the formation of carbonic anhydride the volume produced is equal to the oxygen used; consequently if the gas analysed contains only nitrogen, oxygen, and carbonic anhydride, the mixture will have the same volume as the original air. The volume, therefore, of the nitrogen present in the 100 c. c. of gas used will be 79 c. c., whilst the sum of the oxygen and carbonic anhydride will be 21 c. c. Now, in the formation of carbonic oxide the volume of this gas formed is double that of the oxygen required for its production; consequently for every 79 c. c. of nitrogen present in the air used, there will be a volume of oxygen and carbonic oxide greater than 21 c. c.; the more carbonic oxide formed the greater the increase in volume; therefore for every 100 c. c. of air used we shall have more than 100 c. c. of combustion products, if carbonic oxide be one of the products.

Knowing the volume of nitrogen present the question may be solved as follows:—

Let n = volume of nitrogen found.
x = sum of volumes of oxygen and carbonic anhydride.
y = volume of carbonic oxide.

Hence—

$$\frac{y}{2} = \left\{ \begin{array}{l} \text{oxygen which went to form carbonic} \\ \text{oxide.} \end{array} \right.$$

$$\therefore x + \frac{y}{2} = \left\{ \begin{array}{l} \text{total volume of atmospheric oxygen} \\ \text{used during air combustion.} \end{array} \right.$$

The volume of mixed gases operated on is 100 c. c.

(1) $\therefore x + y + n = 100.$

Since 100 parts of air contain 21 of oxygen and 79 of nitrogen, we have—

$$\frac{21}{79} n = \left\{ \begin{array}{l} \text{oxygen associated with n parts of} \\ \text{nitrogen for the combustion.} \end{array} \right.$$

Hence:—$\frac{21}{79}n = x + \frac{y}{2}$

From (1) we have $x = 100 - y - n$

$$\therefore \frac{21}{79}n = 100 - y - n + \frac{y}{2}$$

Hence:—(2) $100\,n = 7900 - \frac{79\,y}{2}$

Substituting in this formula the value found for n, we readily arrive at the volume of carbonic oxide present, and deducting this amount from the total volume absorbed by the ammoniacal copper solution, we also have the oxygen present.

EXAMPLE.—100 c. c. of gas lost in volume 5 c. c. in the first cylinder, and after passing from the second cylinder, the gas measured 70 c. c.; find the amount of carbonic oxide and oxygen respectively present:—

From the formula (2) we have—

$$100 \times 70 = 7900 - \frac{79\,y}{2}$$

$$y = \frac{900 \times 2}{79} = 22{\cdot}78 \text{ c. c. of CO.}$$

The absorption in second cylinder was $95 - 70 = 25$, and the oxygen present is $25 - 22{\cdot}78 = 2{\cdot}22$.

Percentage composition of the mixture:—

Carbonic anhydride	(observed) .	5·00
Nitrogen . . .	,,	70·00
Carbonic oxide .	(calculated) .	22·78
Oxygen . . .	,, .	2·22
		100·00

As the apparatus is intended for industrial investigations, it is of course desirable to have as few calculations as possible. To accomplish this desirable object Fichtet prepared the following Tables, so that when both carbonic oxide and free oxygen are present the amounts may be sought in the Tables. Table I. gives the increase of volume of 100 c. c. of *air* when 1 c. c. to 42 c. c. have been transformed into carbonic oxide (CO). Table II. gives the amount of oxygen and carbonic anhydride together, the volume of CO, and the quantity of air required for its formation; this latter Table is the one most required.

TABLE I.

Increase in 100 c. c. of Air when any of the Oxygen is transferred into CO.

N.	O.	CO.	Final volume.
79	21·00	0	100·00
79	20·50	1	100·50
79	20·00	2	101·00
79	19·50	3	101·50
79	19·00	4	102·00
79	18·50	5	102·50
79	18·00	6	103·00
79	17·50	7	103·50
79	17·00	8	104·00
79	16·50	9	104·50
79	16·00	10	105·00

N.		O.		CO.		Final volume.
79	...	15·50	...	11	...	105·50
79	...	15·00	...	12	...	106·00
79	...	14·50	...	13	...	106·50
79	...	14·00	...	14	...	107·00
79	...	13·50	...	15	...	107·50
79	...	13·00	...	16	...	108·00
79	...	12·50	...	17	...	108·50
79	...	12·00	...	18	...	109·00
79	...	11·50	...	19	...	109·50
79	...	11·00	...	20	...	110·00
79	...	10·50	...	21	...	110·50
79	...	10·00	...	22	...	111·00
79	...	9·50	...	23	...	111·50
79	...	9·00	...	24	...	112·00
79	...	8·50	...	25	...	112·50
79	...	8·00	...	26	...	113·00
79	...	7·50	...	27	...	113·50
79	...	7·00	...	28	...	114·00
79	...	6·50	...	29	...	114·50
79	...	6·00	...	30	...	115·00
79	...	5·50	...	31	...	115·50
79	...	5·00	...	32	...	116·00
79	...	4·50	...	33	...	116·50
79	...	4·00	...	34	...	117·00
79	...	3·50	...	35	...	117·50
79	...	3·00	...	36	...	118·00
79	...	2·50	...	37	...	118·50
79	...	2.00	...	38	...	119·00

N.	O.	CO.	Final volume.
79	1·50	39	119·50
79	1·00	40	120·00
79	0·50	41	120·50
79	0·00	42	121·00

Table II.

Number of c. c. of CO produced by the Combustion of Carbon in Air, and the corresponding quantities of Nitrogen, in 100 *c. c. of Gas to be Analysed.*

N.	O and CO_2 together.	CO.	Quantity of air necessary to produce the CO.
79·00	21	0·00	100·00
78·605	20·395	1·00	99·50
78·21	19·79	2·00	99·00
78·00	19·47	2·53	98·74
77·815	19·185	3·00	98·50
77·42	18·58	4·00	98·00
77·025	17·957	5·00	97·50
77·00	17·94	5·06	97·47
76·63	17·37	6·00	97·00
76·135	16·865	7·00	96·50
76·00	16·40	7·60	96·25
75·84	16·16	8·00	96·00
75·405	15·595	9·00	95·50
75·05	14·95	10·00	95·00
75·00	14·87	10·13	94·94
74·655	14·345	11·00	94·50
74·26	13·74	12·00	94·00

N.	O and CO_2 together.	CO.	Quantity of air necessary to produce the CO.
74·00	13·34	12·66	93·67
73·865	13·135	13·00	93·50
73·47	12·53	14·00	93·00
73·075	11·925	15·00	92·50
73·00	11·81	15·19	92·41
72·68	11·32	16·00	92·00
72·286	10·714	17·00	91·50
72·00	10·28	17·72	91·14
71·89	10·11	18·00	91·00
71·495	9·505	19·00	90·50
71·10	8·90	20·00	90·00
71·00	8·75	20·25	89·88
70·705	8·295	21·00	89·50
70·31	7·69	22·00	89·00
70·00	7·21	22·79	88·61
69·925	7·085	23·00	88·50
69·52	6·48	24·00	88·00
69·125	5·875	25·00	87·50
69·00	5·68	25·32	87·34
68·73	5·27	26·00	87·00
68·235	4·765	27·00	86·50
68·00	4·15	27·85	86·08
67·94	4·06	28·00	86·00
67·505	3·495	29·00	85·50
67·15	2·85	30·00	85·00
67·00	2·62	30·58	84·81
66·755	2·245	31·00	84·50

N.	O and CO_2 together.	CO.	Quantity of air necessary to produce the CO.
66·36	1·64	32·00	84·00
66·00	1·09	32·91	83·55
65·965	1·035	33·00	83·50
65·67	0·33	34·00	83·00
65·29	0·00	34·71	82·65

To illustrate the use of Table II. we will suppose that 100 c. c. of a gas is to be analysed. It is passed through E, a diminution of 5·5 c. c. in the volume takes place, due to the absorption of the CO_2. The remainder of the gas (100—5·5=94·5) is then passed through F; after this has taken place 69 c. c. of gas remains unabsorbed, which gas is nitrogen; therefore 25·5 c. c. of gas has been absorbed in F, which represents the carbonic oxide and oxygen together. On referring to Table II. we find that 69 of nitrogen corresponds to 25·32 of carbonic oxide; therefore the oxygen the gas contained was 0·18 c. c. as 25·5 – 25·32=0·18. The volume of air required for the formation of 25·32 c. c. of CO is, as we learn from the Table, 87·34 c. c.

The following was, therefore, the composition of the 100 c. c. of the gas :—

N	69·00	observed.
CO	25·32	taken from the Table.
CO_2	5·50	observed.
O	0·18	difference.
	100·00	

The errors that may occur in the results obtained by this apparatus are of no importance in industrial investigations ; the one of most importance arises from the unequal solubility in water of the different gases operated upon. This may be avoided in scientific investigations by substituting mercury for the acidulated water.

It is only necessary to vary the absorbent liquids to make the apparatus applicable for the estimation of most gases.

APPENDIX.

A.

What is Coal?—"The owners of an estate at Torbanehill, in the county of Linlithgow, had granted a lease of the whole coal, ironstone, limestone, and fire-clay contained within it, except copper and any other minerals whatsoever than those above specified; and it should be remarked that the true coal measures of geologists were proved to exist under the same estate. In the course of working, the lessees extracted a combustible mineral of great value as a source of coal gas, and realised a large profit by the sale of it as gas coal. The lessors, thereupon, denied that the mineral in question was coal, and disputed the right of the lessees to work it. At the trial there was a great array of scientific men on each side, including chemists, botanists, geologists, and microscopists; and of practical gas engineers, coal viewers, and others, there were not a few. On the one side it was maintained that the mineral was *coal*, and on the other it was a *bituminous* schist. The evidence, as might be supposed, was most conflicting. The judge, accordingly, ignored the scientific evidence altogether, and summed up as follows:—'The question for you (the jury) to consider is not one of motives, but what is this mineral? Was it coal in the language of those persons who deal and treat with that matter and in the ordinary language of Scotland? *because to find a scientific definition of coal after what has been brought to light within the last five days is out of the question.* But was it coal in the common use of that word, as it must be understood to be used in language that does not profess to be the purest science, but in the ordinary acceptation of business transactions reduced to writing? Was it coal in that sense? That is the question for you to solve, for you to determine.' The jury found that it was coal. Subsequently to this trial the same mineral was pronounced *not to be coal* by the authorities of Prussia, who accordingly directed it not to be entered by the custom-house officers as coal."—(*Percy.*)

B.

Mr. Goldsworthy Gurney in the beginning of the year 1851 employed carbonic anhydride as an extinguisher of combustion on a gigantic scale. The object of the experiment was to extinguish a fire in a colliery, about seven miles from Stirling, which had raged for about thirty years over an area of twenty-six acres. A sum of 16,000*l.* was expended in surrounding the fire with a puddle-wall, to prevent its extending to other workings. The wall took five years to build, the workmen being frequently driven back, and obliged to recommence at a greater distance from the fire. After its completion it required constant attention, for if the fire had once passed it would have been very difficult to have again surrounded it. It cost the Earl of Mansfield, the owner of the property, in consequence, about 200*l.* a-year in keeping it repaired. The fire being thus, as it were, corked and bottled up, ought to have become extinguished for want of air to support the combustion. But as no part of the fire mine was deeper than twenty fathoms, and as some of it ran at no great distance below the surface, it obtained a sufficient supply of air from without, as well as through the leakages in the puddle-wall, to maintain a smouldering, volcano-like existence.

Mr. Gurney had not only to extinguish the fire, but he had also to accomplish what was quite as difficult, the cooling down of the mine, so that when the air was admitted the coal should not re-ignite. He obtained the carbonic anhydride by passing air through an immense coke fire in a brick furnace; this gas, along with the nitrogen of the air, was forced through the furnace along an iron cylinder down the shaft, and through a steam jet into the mine; water in the form of the finest spray was also driven along with the gas. After having blown in about 8,000,000 cubic feet of the gas at the rate of about 7000 cubic feet per minute, it was found by exit of the gas through the leakages and shafts that the mine was fully charged with it. At the end of three weeks the fire was extinguished, the mine during that time having been kept fully charged with the gas. Fresh air was then admitted by the jet. After a time the action was reversed, the air charged with moisture being thus drawn out. The air that was drawn out gradually decreased at the rate of about 6° a day. After about one month's operations, the down-cast shaft was uncovered, and the temperature of the mine was found to be about 98° F.

C.

The following Table gives the names of the constituents and their composition which have been discovered in the gaseous, liquid, and solid products formed in the destructive distillation of coal; they may be classed in reference to their illuminating properties under the following heads:—

ELEMENTARY BODIES.

HYDROGEN, H; NITROGEN, N; CARBON (COKE), C.

Hydrocarbons, or Bodies containing Carbon and Hydrogen, of various Series.

C_nH_{2n+2}	C_nH_{2n}	C_nH_{2n-2}	C_nH_{2n-6}	C_nH_n	C_nH_{n-2}	C_nH_{n-4}	C_nH_{n-6}	C_nH_{n-8}
Methane, CH_4 Ethane, C_2H_6 Propane, C_3H_8 Butane, C_4H_{10} Pentane, C_5H_{12} &c. &c.	Ethene, C_2H_4 Propene, C_3H_6 Butene, C_4H_8 Pentene, C_5H_{10} &c. &c.	Ethine, C_2H_2 Propine, C_3H_4 &c. &c.	Benzene, C_6H_6 Toluene, C_7H_8 Isoxylene, C_8H_{10} Methyl-Toluene, C_8H_{10} Cumene, C_9H_{12} Pseudo-Cumene, C_9H_{12} Mesitylene, C_9H_{12}	Styrolene, C_8H_8 Metastyrolene, $(C_8H_8)n$	Cymene, $C_{16}H_{14}$ Napthalene, $C_{10}H_8$	Phenanthrene, $C_{14}H_{10}$ Anthracene, $C_{14}H_{10}$	Pyrene, $C_{16}H_{10}$ Chrysene, $C_{18}H_{12}$	Idrialene, $C_{22}H_{14}$

Hydrocarbons containing Nitrogen.		Hydrocarbons containing Oxygen.	Various "Inorganic" Bodies.
Aniline, C_6H_7N	Parvoline, $C_9H_{13}N$	Phenol, C_6H_6O	Ammonia, NH_3
Toluidine, C_7H_9N	Coridine, $C_{10}H_{15}N$	Cresol, C_7H_8O	Carbonic Oxide, CO
Pyrrol, C_4H_5N	Rubidine, $C_{11}H_{17}N$	Phlorol, $C_8H_{10}O$	Carbonic Dioxide, CO_2
Pyridine, C_5H_5N	Viridine, $C_{12}H_{19}N$		Sulphurous Anhydride, SO_2
Picoline, C_6H_7N	Leucoline, C_9H_7N		Sulphuretted Hydrogen, SH_2
Lutidine, C_7H_9N	Lepidine, $C_{10}H_9N$		Carbon Disulphide, CS_2
Collidine, $C_8H_{11}N$	Cryptidine, $C_{11}H_{11}N$		Sulphocyanic Acid, HCNS
			Aqueous Vapour, H_2O

1. The combustible non-illuminating constituents.
2. The illuminating hydrocarbons.
3. The non-essential constituents as regards illumination.
4. The impurities.

The members of the first-class are hydrogen and carbonic oxide; they amount to from 30 to 60 per cent. of coal gas.

The specific gravity of the hydrocarbons varies from 0·553 (air = 1·0) to 6·635.

THE END.

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