reduced to standard conditions is maintained constant to within $\frac{1}{10}$ per cent. The corrections effected over a period of a month are automatically recorded on a drum revolving above the device. The method of mounting the meter drum loose on a screwed axle also prevents the occurrence of accidents should the gas supply be temporarily cut off and resumed later, or should the water flow cease. The possible interference of a mouse with the righting of the bucket after emptying is also ingeniously provided for.

The Calorimeter Proper.—This is shown in vertical section in Fig. 4. A and B are the hot and cold water chambers respectively; C is the heat interchanger, in which the heat of the products of combustion derived from gas burning at the fused-silica burner, D, is communicated to the stream of water. A silica dome is disposed above the flame. The interchanger is made of sheet-lead closely folded into fifteen zig-zags round the central combustion space. Narrow up-cast water-ways are then formed on one side of the sheet, and down-cast gas-ways on the other side. The heated water passes to B through the narrow neck in the double partition, E, a device introduced by Prof. Boys to prevent the calorimeter indicating more heat than is produced by the gas. The copper cylinder, F, fixed to the brass ring, G, is so proportioned, that loss of heat from the upper part of the hot-water compartment is compensated by the equal gain from the cylinder lower down by the heat interchanger.

The operative thermometers, H and J, are of brass, and are filled with amyl alcohol. They are closed with corrugated brass covers. A lever system utilising the third dimension of space, magnifies the deformation of the respective covers occurring with change of temperature, and the net difference of temperature of the two thermometers, due to heating, controls the position of an inked pen recording on a roll of paper, seen on the right of Fig. 1, kept in motion by the clock. On the paper parallel lines are ruled during the rotation, indicating definite percentage departures of the actual measured calorific value of the gas from the declared calorific value. Time indications are in like manner impressed upon the record. An integrating device shown on the right of Fig. 4, operating after the manner of the Amsler planimeter and controlled by the position of the recording pen, averages the departures of the calorific value of the gas from the declared calorific value since the indicator was last set to zero, *i.e.*, since the beginning of the quarter, so that, for example, the integrator indicating +5 would signify a 5-day 1 per cent. excess of calorific value, or a 1-day 5 per cent. excess, etc.

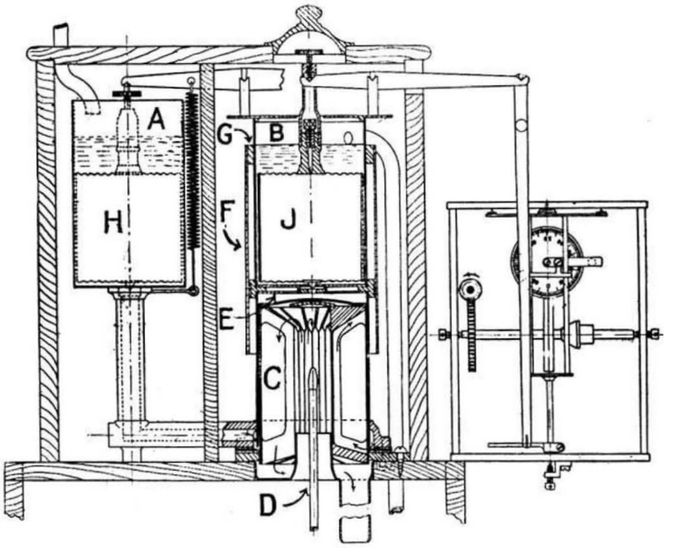

FIG. 4.

The writer is extremely obliged to Prof. Boys for the kind manner in which he has afforded information concerning the instrument, and to Messrs. Griffin and Sons for providing the illustrations reproduced in this article.

The Earth's "Crust" and its Composition.

By THOMAS CROOK.

THE term "crust" is frequently used in dealing with the constitution of the earth, but is seldom defined. It is a convenient scientific term to apply to the earth's outermost shell, the only portion of which geologists have much positive knowledge, and if it is put to scientific use, it should be defined, although a definition of it may involve some hypothesis as to the physical condition of the earth's interior.

According to Arrhenius, who assumes that the temperature-gradient observed in continental areas is persistent in depth, the temperature of the earth's interior greatly exceeds that of the critical temperature of the materials occurring there. He infers therefore that the interior is for the most part gaseous though rigid, and that this gaseous core is separated by a molten layer from an outer solid shell about 40 miles thick. Osmond Fisher assumed a molten condition at a depth of 25 miles. To those who accept this view, the term "crust" has a very real and simple significance: it is the thin, solid, outer shell of the earth, underlain by molten magma.

At the present time, however, this hypothesis appears not to be widely held among geophysicists, most of whom follow Lord Kelvin, Sir George Darwin, and other eminent authorities who have shown good reasons for rejecting the hypothesis of a molten interior at such depths as postulated by Fisher and Arrhenius, and who claim that the earth is solid throughout. For those who adopt this view the definition of the earth's "crust" is a more difficult matter.

The prevalent view at the present day as regards the constitution of the earth's interior is that it consists of an inner core of nickel-iron about 6200 miles in diameter, surrounding which is a silicate shell some 900 miles in thickness. The silicate shell is largely ultra-basic and basic. Lying on the thick shell of basaltic rock, which girdles the whole earth, is a comparatively thin and discontinuous layer of more siliceous rock-matter (granite and gneiss), on which the sedimentary rocks have been formed in and around the continental areas. According to the conception of a solid earth so constituted, we clearly have no satisfactory basis for defining the earth's "crust" in terms of the kind of rock of which it is made up, and unless it can be shown that, at some convenient and fairly uniform depth, the rock-substance of the earth undergoes a critical change in its physical condition at the temperature and pressure prevailing there, the only available alternative is to define the "crust" in a more arbitrary manner in terms of depth.

One way of doing this is to limit its thickness, as some authors do, to that outer portion of the earth of which we may be said to have observational knowledge. The maximum depth at which rocks observable at the surface of the earth have been formed is quite an important geological problem from the economic as well as from the scientific viewpoint, and one that appears never to have been treated adequately. It may, however, perhaps safely be inferred that, by observation of surface geological features, we have a knowledge of the earth down to a depth of more than 5 miles, but considerably less than 10 miles.

In their most recent estimate of the average composition of the earth's "crust," Drs. F. W. Clarke and H. S. Washington, of the United States Geological Survey, give its average composition down to depths of 10 and 20 miles. The detailed statement of their results has not yet been published, but is to be issued as a Professional Paper by the U.S. Geological Survey. Pending the publication of the detailed report, however, they have given a brief account of their results in the Proceedings of the National Academy of Science (1922, vol. 8, p. 108).

The method adopted by them for ascertaining the average composition of the lithosphere is to take the average of trustworthy analyses of igneous rock specimens collected from various parts of the earth's surface. They have included 5159 analyses. Averages are given separately for the igneous rocks of the United States; North America other than the United States, including Greenland; Central and South America; Europe; Africa and Asia; Australasia, Polynesia and Antarctica. In computing the averages for these various regions the sum total of each constituent was divided by the total number of analyses of specimens from the region dealt with. In calculating the composition of the earth's "crust" as a whole, the proportions of the lithosphere, hydrosphere and atmosphere for a depth of ten miles were taken as follows:—lithosphere 93 per cent., hydrosphere 7 per cent., and atmosphere 0·03 per cent. The lithosphere is assumed to be made up as follows:—igneous rocks, 95 per cent.; shale, 4 per cent.; sandstone, 0·75 per cent.; and limestone, 0·25 per cent. Figures are given for the rarer as well as for the commoner elements.

The following is the result obtained for the average chemical composition of the igneous rocks of the earth:—

AVERAGE IGNEOUS ROCK.

	Per cent.		Per cent.
SiO_2	59·12	F	0·030
Al_2O_3	15·34	S	0·052
Fe_2O_3	3·08	$(Ce,Y)_2O_3$	0·020
FeO	3·80	Cr_2O_3	0·055
MgO	3·49	V_2O_3	0·026
CaO	5·08	MnO	0·124
Na_2O	3·84	NiO	0·025
K_2O	3·13	BaO	0·055
H_2O+	1·15	SrO	0·022
CO_2	0·101	Li_2O	0·008
TiO_2	1·050	Cu	0·010
ZrO_2	0·039	Zn	0·004
P_2O_5	0·299	Pb	0·002
Cl	0·048		
			100·000

The following table shows the estimated percentages of the commoner elements in the lithosphere, hydrosphere and atmosphere:—

ELEMENTS IN THE LITHOSPHERE, HYDROSPHERE, AND ATMOSPHERE.

	1	2	3	4
Oxygen	49·19	47·80	46·68	46·41
Silicon	25·71	26·65	27·60	27·58
Aluminium	7·50	7·79	8·05	8·08
Iron	4·68	4·88	5·03	5·08
Calcium	3·37	3·49	3·63	3·61
Sodium	2·61	2·72	2·72	2·83
Potassium	2·38	2·48	2·56	2·58
Magnesium	1·94	2·01	2·07	2·09
Hydrogen	0·872	0·497	0·145	0·129
Titanium	0·648	0·684	0·696	0·720
Chlorine	0·228	0·162	0·095	0·096
Phosphorus	0·142	0·150	0·152	0·157
Carbon	0·139	0·095	0·149	0·051
Manganese	0·108	0·116	0·116	0·124
Sulphur	0·093	0·086	0·100	0·080
Barium	0·075	0·078	0·079	0·081
Chromium	0·062	0.065	0·066	0·068
Zirconium	0·048	0·050	0·052	0·052
Vanadium	0·038	0·040	0·041	0·041
Strontium	0·032	0·034	0·034	0·034
Fluorine	0·030	0·030	0·030	0·030
Nickel	0·030	0·031	0·031	0·031
Nitrogen	0·030	0·016	..	..
Cerium, Yttrium	0·019	0·020	0·020	0·020
Copper	0·010	0·010	0·010	0·010
Lithium	0·005	0·005	0·005	0·005
Zinc	0·004	0·004	0·004	0·004
Cobalt	0·003	0·003	0·003	0·003
Lead	0·002	0·002	0·002	0·002
Boron	0·001	0·001	0·001	0·001
Glucinum	0·001	0·001	0·001	0·001
	100·000	100·000	100·000	100·000

1. Average composition. Ten-mile crust, hydrosphere, and atmosphere.
2. Average composition. Twenty-mile crust, hydrosphere, atmosphere.
3. Average composition. Ten-mile crust, igneous and sedimentary rocks.
4. Average composition. Ten-mile crust. Igneous rocks.

A serious defect in the method of procedure on which the above estimates by Clarke and Washington are based is that it makes no allowance for the relative magnitude of the different kinds of rock of which the lithosphere is composed. They admit this defect, but claim that any errors involved are likely to be compensating (*Journ. Franklin Inst.*, 1920, vol. 190, p. 770). Their claim can scarcely be allowed, however, even for the outer 10 miles of the "crust," and still less can it be allowed down to a depth of 20 miles.

As to the relative proportions of the rocks composing the lithosphere at this depth, even at 10 miles, we have as yet no positive knowledge, but the distribution of igneous rocks at the surface of the earth, and a comparison of oceanic and continental regions, give us some important facts to guide our reasoning on this matter. We are probably not far from the truth if we assume that the granitic portion of the lithosphere is largely restricted to the continental regions of the earth, and its thickness may not exceed an average of about 5 miles. If so, assuming this granite layer in continental regions to contain on an average 70 per cent. of silica, and assuming that it is underlain to a depth of 10 miles from the surface by basalt containing on an average 48 per cent. of silica, this would give us a silica percentage of about 59 for the average igneous rock of the lithosphere in continental regions down to a depth of 10 miles, which is in agreement with the average of the igneous rock of the " crust " as estimated by Clarke and Washington.

It should be noted that this takes no account of the " crust " of the oceanic regions, which is probably in large part basaltic. We may for the purpose of this argument assume that the granite shell of continental regions covers half the earth. This is an extravagant assumption, but as it doubtless errs substantially in exaggerating the acidity of the " crust," the error is on the right side so far as the present argument is concerned. If we further assume the sub-oceanic " crust " down to a depth of 10 miles to be basaltic, and to contain on an average 48 per cent. of silica, this would give us an average igneous rock containing about 53½ per cent. of silica for the outer 10 miles of the lithosphere all round the earth.

Extending our considerations to a depth of 20 miles, there can be little doubt that we should regard the deeper 10 miles as on the whole more basic than the basaltic material of the outer 10 miles, and it is reasonable to assume that this deeper layer of basalt does not contain on the average more than 46 per cent. of silica. If we make this assumption, then the average rock of the earth's " crust " as a whole down to a depth of 20 miles would contain not more than about 50 per cent. of silica.

Comparing these with the figures given above by Clarke and Washington, the inference we draw is that they have probably much understated the basicity of the earth's " crust." Their average down to a depth of 10 miles is, as we have seen, only acceptable for continental regions, and cannot be admitted for the earth as a whole. Still less can their average for the lithosphere down to a depth of 20 miles be admitted, for, as we have seen, there is good reason for believing that the average rock down to this depth probably corresponds to a gabbro, containing about 50 per cent. of silica, rather than, as they infer, to a granodiorite containing 59 per cent. of silica.

This question of the average composition of the earth's " crust " has important bearings on many scientific and economic problems. It is quite commonly assumed that the average igneous rock is intermediate in composition, and that granitic and basaltic eruptives are products of differentiation derived from intermediate magmas. It seems highly probable, however, that the average igneous rock of the earth's crust is basic ; and although differentiation does undoubtedly play an important part in the formation of igneous rocks, the claim that granites and basalts are in general differentiates from magmas of intermediate composition has no adequate foundation in the facts known to us concerning the petrology of the earth.

Centenary of the Death of William Herschel.

ON August 25, 1822—a hundred years ago—William Herschel died at Slough, aged eighty-three years and nine months. His scientific activity had continued almost to the end of his long life. His last published paper was read before the Royal Astronomical Society (of which he was the first President) in June 1821. It is the only one of his seventy memoirs which was not published in the Philosophical Transactions, of the yearly volumes of which for the years 1780 to 1818 inclusive only those for 1813 and 1816 contain nothing by him, while not a few volumes include several papers from his hand. Even in the last year of his life, when his son, under his continual guidance, made and figured the 18¾-inch mirror, which was afterwards used by Sir John Herschel at Slough and at the Cape, it is recorded that " the interest he took in this work and the clearness and precision of his directions showed a mind unbroken by age and still capable of turning all the resources of former experience to the best account."

When Herschel, on March 1, 1774, began to keep a record of what he saw in the heavens with telescopes made by himself, it was natural that he should for some years show no decided preference for any particular branch of astronomy. At first he paid some attention to the planets, and determined the rotation-periods of Jupiter and Mars. But it did not escape his clear perception very long that what was urgently required at that time was a systematic study of the vast number of celestial bodies outside the solar system. If Herschel had not early grasped this fact, and persevered all the rest of his life in his devotion to sidereal astronomy, he would never have become a great astronomer, but would merely, like his contemporary, Schröter, have been known as an indefatigable observer who occasionally did some good work. But on his way from the solar system out into space beyond it Herschel found a new planet (Uranus), about twice as far from the sun as what had up to then been considered the outermost planet. This was not a lucky accident, but a discovery which was bound to be made sooner or later by an observer who searched the heavens as systematically as he did. It was the first time since the prehistoric ages that a new planet was discovered. Herschel afterwards found two satellites of Uranus and two of Saturn, but his principal work was always on subjects connected with sidereal astronomy.

" A knowledge of the construction of the heavens has always been the ultimate object of my observations." This was the opening sentence of his paper of 1811, and as he had said much the same in the concluding words of his first paper (of 1784) on that subject, we see how faithful he remained to the plan of work he had adopted early in his scientific career.