The Air and its Ways.[1]

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THE physical problems of the weather map have not been solved, for the subject is inherently difficult. In the first place, the atmosphere is on such an immense scale that its behaviour is not to be brought under the principles of physics without much trouble, and, I may add, many mistakes. The most confident theories of the past are flatly contradicted by facts which have come to light since the investigation of the atmosphere was extended to the upper air by balloons, kites, kite-balloons, and more recently by airships and aeroplanes. We have now many facts about the atmosphere up to 20 kilometres at our disposal. They are, of course, not necessary for the formation of a correct theory, because no new principles are involved, but they are invaluable for the purpose of the verification or contradiction by which hypotheses get moulded into consistent theory.

The behaviour of air in bulk is so entirely different from that of the laboratory sample that the ways of the air are, indeed, as peculiar as those of "the heathen Chinee." The air as we know it in the laboratory is a very mobile fluid, yet in the atmosphere it manages to take on a sufficiency of the character of an elastic solid. It does not go in the way it is pushed; pushed north it goes east, and pushed east it goes south. The condition for getting it to go north is that it should be pushed west. If you blow a jet of air straight upward you may find that part of the effect is a vortex whirling around you. In front of its fire—the sun—the air will very likely get colder instead of warmer; losing heat by exposure to the clear sky on a cold night, it may get warmer. In spite of all that is taught in the laboratory about the levitating effect of warmth, cold air floats above us with warmer air beneath. If you tell the air that warm air rises, it winks an eye and interjects an "if" and a "when." If the Olympian gods felt cold and thought to make themselves warmer by stirring up their chilly air with the warmer air enjoyed by mortals down below them, they would be disappointed. Stirring would make them colder and us warmer. Shake air up violently, water falls out of it; and if the shaking went on long enough the air would become intolerably dry, very cold at the top and very warm at the bottom. Not only has the air the innate capacity for these conjuring tricks, but it never, or scarcely ever, fails to use them.

The General Problem of the Science of Meteorology.

Yet, underlying the work that is done in meteorology officially or unofficially, there is, and has been all the time, a definite purpose to bring our knowledge of the air into relation with the laws of physics as established in the laboratory, and, therefore, particularly with the laws of energy.

The Fundamental Facts.

There are two sides to the study of the air and its ways which can be pursued by different people who may never meet each other. One is the observation and collection of the facts about the weather from every part of the world; the other is the interpretation of facts by dynamical and physical reasoning. Nothing—at least nothing useful—can be done without real facts; but real facts do not, as a rule, explain themselves. The composition of air at different levels has been computed, and the results for one hundred kilometres are different according to Humphreys, Wegener, and Chapman. Below the level of 20 km. we are not troubled with changes of composition except those in the amount of water-vapour. The meteorological facts may be expressed by maps showing coast lines and orographic features, surface-temperature in January and July and its discontinuities at the coast lines, water-vapour at the surface in July, cloud, rainfall over the land, winds over the sea, and pressure over the globe in the same month.

Winds and temperatures in the upper air can be illustrated by models in cardboard. That for temperature shows the general run of the isothermal surfaces and the modifications caused by the introduction of local cyclones and anticyclones.

The Atmosphere a Great Steam Engine.

We are all agreed that the atmosphere is in reality a great engine, partly an air engine, but more effectively a steam engine, or at least a moist-air engine. Now the essential parts of a steam engine are a boiler to supply it with heat, a condenser at a lower temperature to absorb the surplus heat, and a fly-wheel to maintain the continuity and uniformity of its action. We describe the action of the engine as taking a supply of heat from the boiler, giving out heat to the condenser, and converting into work, useful or otherwise, the difference between the heat taken in and that given out.

Can we rightly use such language about the atmosphere and usefully contemplate the ways of the air from that point of view? I think we can, though the analysis of the phenomena from that point of view is difficult. The boiler is certainly there; I have shown it to you in the distribution of temperature with the great warmth of the equatorial regions. In the map of the distribution of water-vapour I have shown you where the steam is raised. The condenser is there also, partly in the shape of the vast cooling surfaces of the high lands of the arctic and antarctic regions, and of snow-covered mountains generally; but perhaps more effectively in the upper air, particularly in the stratosphere, which at a temperature of

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190a. to 240a. (*i.e.* from 60 to 150 Fahrenheit degrees below freezing point) is certainly cold enough for the purpose, and, for certain reasons which I will not now expound, must be regarded as an effective means of getting rid of heat by radiating it into space.

The Fly-wheel of the Atmospheric Engine.

And what of the fly-wheel and the work done by the engine? Surely the winds, whether of the general circulation or of the local circulation of cyclonic depressions, are a fair representation of the fly-wheel. At the risk of laying myself open to the unpardonable sin of punning, I will point out that the fly-wheel is of enormous importance to flying, because the flyer can either attach himself to it and be carried along with it, or he may have to labour to make headway against it. The choice of these alternatives depends upon the airman's knowledge of its habits and behaviour—of its ways, in fact. The constituent parts of the fly-wheel at any time are the natural air-ways of the world. It was by hanging on to one part of the fly-wheel in the fifteenth century that Columbus discovered America, and by the aid of another portion, just two years ago (June 14, 1919), Sir John Alcock crossed the Atlantic in 16½ hours, and on July 13 of the same year Air Commodore Maitland landed R.34 at Pulham after a journey from New York in 3 days and 3 hours. Its total energy is tremendous, of the order of 100 billion horse-power-hours.

The Polar and Equatorial Circulations in the Upper Air as Parts of the Fly-wheel.

One of the immediate results of the thermal operations is to maintain the great fly-wheel or to start new sections of it in the form of local cyclonic circulations. Omitting these for the moment, I want to put before you some information about that part of the fly-wheel which is expressed by the general circulation. We can do so by distinguishing and ultimately isolating those portions of the atmosphere which represent permanent parts of the general circulation. Our best method of procedure is by way of pressure. We can compute the distribution of pressure for successive levels and verify the computation by the occasional observations of pressure at the various points of observation. We can thence calculate winds to correspond therewith in accordance with the general principle of the relation of pressure to wind, to which reference has already been made, and which finds partial expression in Buys Ballot's law.

A glass model expresses the results most clearly. It is made to show simultaneously on concentric hemispherical glass shades maps of pressure for 2000, 6000, and 10,000 metres. They disclose an enormous body of air extending at the higher levels from the pole or thereabout to latitude 40°, with a protuberance to the equator in the lower levels of the monsoon region. The air circulates about the polar axis in curves not exactly coincident with circles of latitude, but not very different therefrom. This mass of moving air constitutes a very considerable fly-wheel.

The maps also disclose a collection of anticyclonic circulations in the intertropical region lying between a stream of westward-moving air at the equator and a stream of eastward-moving air at about latitude 35°. Thus the margins of the anticyclones form a sort of chain-drive pulling the air from east to west on the equatorial side and pushing the polar circulation eastward. These vast local areas of high pressure are interesting in relation to the tracks of hurricanes, the normal path of which for this part of the year is marked thereon. The lines which separate the high-pressure areas are at the coast lines, and emphasise the meteorological importance of those lines; with one of them the hurricane track is evidently associated.

Local Cyclonic Circulations as Parts of the Fly-wheel.

Among the products of the working of the aerial engine we have included the energy of the circulation of local cyclonic depressions, whether they take the form of the hurricanes of tropical countries or of the milder depressions of our own latitudes. I anticipate no objection to the suggestion that these phenomena are part of the working of the general atmospheric engine; but there is so far no general agreement as to the precise way in which the engine operates to produce these results.

I have recently suggested that the development of a vortex of revolving fluid may be due to the "injector-effect," or, as I prefer to call it, the "eviction-effect," of rising air or falling rain or both combined, and I have put together an apparatus designed to test the effect of the various possible causes in producing a cyclonic vortex when the conditions of relative motion are favourable. I have come to the conclusion that the air is much more easily moved to take up cyclonic circulation than has hitherto been supposed, and, in fact, cyclonic circulation is the natural expression of a part of the kinetic energy of rising air or falling rain, requiring only favourable local conditions for its obvious manifestation. Perhaps I may add that on that ground a volcano in explosive eruption ought naturally to cause a local tornado. The energy of cyclonic motion can therefore be added to the other parts of the atmosphere's fly-wheel with some confidence that it is in accordance with natural fact.

An Indicator Diagram for the Atmospheric Engine.

If this view of the atmosphere is a reasonable one, then we ought to be able to refer the operations of the air to what Maxwell calls an *indicator diagram*, expressing by the area of a closed figure the work done by the air in the course of a cycle of operations represented by the outline of the figure. During the past forty years I have been

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trying to get that diagram in continuation of the work that I used to do with a class at the Cavendish Laboratory, and now I believe I have succeeded, with the assistance of Mr. E. V. Newnham, of the Meteorological Office. The result is not exactly in the form which is familiar to readers of Maxwell, but in the form of an entropy-temperature diagram such as Sir Alfred Ewing uses in his work on the steam engine. With the diagram it ought to be possible to make a reasonable diagnosis of the ways by which air can ascend from the surface, and descend again to be prepared for a repetition of its cycle. We should then replace by reason the guesswork which has hitherto done duty for it. Further, according to the diagram, the best which you can expect from the steam-laden air of the equatorial region, working between the surface and the stratosphere under favourable conditions, is a "brake-horse-power efficiency of 25 per cent." Operations conducted elsewhere will have less efficiency than that. On the whole, it is not very high, but the energy available as indicated by the equivalent of the amount of rain which falls is so enormous that there is no reason to doubt the capacity of the air as a steam engine to develop and maintain the effects which are included in all our varied experience of the air and its ways.

Congress of the Universities of the Empire.

THE second Congress of the Universities of the Empire, which met in Oxford on July 5–8, was as successful as the Congress of 1912. Higher tribute could not be paid to the skill of those who were responsible for its organisation. Thirty-seven overseas universities were represented by ninety-four delegates and twenty-two "representatives," of whom the very large majority had come to England for the express purpose of attending the Congress. The total number of members, including Oxford residents, was about 600. In the printed list we find amongst the delegates the chancellor of New Zealand, the ex-vice-chancellor of Calcutta; the presidents of Alberta, British Columbia, Dalhousie, McGill, Queen's, Kingston, Saskatchewan, and Toronto; the vice-presidents of Montreal and St. Francis Xavier; and the principals of the University Colleges of Pretoria and Johannesburg and of several Indian colleges. When the present cost of ocean travel is taken into consideration, these figures bear eloquent testimony to the belief of the universities of the Empire in their essential unity and to their faith in their common mission.

In one respect the Congress of 1921 far surpassed that of 1912 in attractiveness, and probably in value also. With the greatest generosity the members of the University of Oxford offered the hospitality of their colleges and their homes to all members of the Congress. The meeting together in common rooms and in the houses of their hosts gave great pleasure to the men and women who had come from the most distant parts of the King's Dominions. The opportunities thus afforded of intercourse and of informal discussion are likely to produce results more important in their bearing upon the practice of teaching and administration than the speeches made in the South Hall of the Examination Schools.

Opportunities of consultation and of the comparison of experience are being further enlarged by the application of a scheme of visits which was tried on a smaller scale and in a somewhat tentative way in 1912. For a month all delegates from overseas are the guests of the home universities. Before Congress met they were given the choice of visiting Reading, Bristol and Cardiff, or Dublin and Belfast. Returning to London, as the guests of the University, they visited its schools and colleges on June 30 and July 1 and 2. On July 4 the Government entertained them, together with the delegates of the home universities, at a luncheon over which Mr. A. J. Balfour presided. On the following morning they travelled by special train to Oxford, where the congress was opened by the chancellor of the University, Lord Curzon. From Oxford the delegates from overseas proceeded to Cambridge and thence to either Edinburgh and St. Andrews, or Glasgow and Aberdeen. They will return in three parties *via* Durham, Newcastle, or Sheffield to Manchester or Liverpool, and will end their tour either in Birmingham or in Leeds.

As the proceedings of Congress have been reported in the daily Press, it will suffice here to mention only some points of special interest to men of science. As was fitting at a meeting in Oxford, the first session was devoted to the consideration of the balance of studies—the place of the humanities in the education of men of science, and of the physical and natural sciences in general education. Many wise things were said by the champions of a literary education. Prof. Desch and Prof. Whitehead spoke for those concerned with the education of students of science. Prof. Desch urged the necessity of including a large measure of humanistic instruction and study in the training of men of science, but proposed that it should take a novel form. In place of balancing the specialised courses in science by a certain number of equally specialised courses in the humanities, he would endeavour to bring the two into closer relationship by making the teaching of science historical, literary, and sociological. If scientifically trained men are to take their proper position in the community they must have "a vision of knowledge in its true proportions and perspective." "The most important safeguard against a limited vision is to be found in the historical spirit." Teachers should show to their students how their sciences grew, should

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