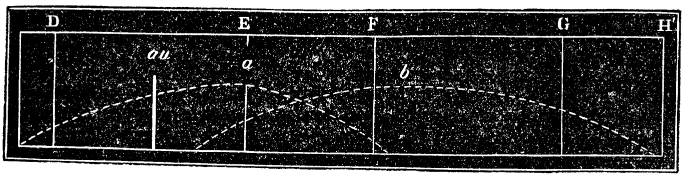
the brightest part of this band, as shown in the accompanying figure.

"In this diagram (of a normal spectrum), curve *a* [which Mr. Capron calls the phosphorescence curve] is deduced from the spectrum of phosphoretted hydrogen, curve *b* from Professor Angström's spectrum of the violet pole of air-vacuum tubes; *a u* is the principal auroral line." This figure is apparently intended to represent the facts under ordinary laboratory conditions; but Mr. Capron states, that according to Lecoq de Boisbaudran, when the flame of phosphoretted hydrogen is artificially cooled, the bands of the spectrum become intensified, and in such a way that the brightest portion of each band is shifted toward the red end of the spectrum. Mr. Capron appears to think, that, under the intense cold of the auroral regions, one of these bands might become the line *a u*.



E. H. HALL.

LETTERS TO THE EDITOR.

Secular increase of the earth's mass.

THE thoughtful and suggestive researches of Ebelmen and T. Sterry Hunt, on the chemical and geological relations of the earth's atmosphere,[1] have led me to some further deductions, which seem to increase the interest in this field of inquiry. The general tendency of these studies is to show that the chemical transformations in progress upon the earth involve the fixation of a larger volume of atmospheric constituents than could probably have ever existed in the atmosphere at one time, and that they must consequently have arrived from interplanetary space.

1. *The carbonates.* — It is generally agreed, as first shown by Hunt, that the carbonates of lime and magnesia have arisen chiefly through the interactions between carbon dioxide of the atmosphere, the decomposing silicates of the earth's crust, and the chloride of calcium of the ocean. The carbon dioxide has therefore been contributed by the atmosphere. To what does this contribution amount? We may assume, without material error, that the carbonates here in question are all calcium carbonate, with a specific gravity of 2.72. Then, the mean pressure of the atmosphere being about 14.7 pounds avoirdupois on a square inch, a little calculation shows that an amount of carbon dioxide in the atmosphere sufficient to double its pressure would yield only 8.627 metres of limestone. An amount sufficient to cause a pressure of 80 atmospheres would suffice for the formation of limestones equal to only a fortieth (.02265) of the hundred thousand feet which, for this purpose, may be assumed as the thickness of the stratified rocks. But a pressure of 80 atmospheres at a temperature of 30° C. produces liquefaction of carbon dioxide. The actual proportion of limestones and dolomites in the earth's crust is about one-eighth, as I have shown by recent studies. This amount would yield, by the liberation of all its carbon dioxide, a pressure of 441.6 atmospheres. If we consider the limestones and dolomites formed since the period of the coal-measures, the proportion required to yield, on the liberation of its carbon dioxide, a pressure of 80 atmospheres, would be only a twenty-second (.04469) of all the post-carboniferous strata. The actual proportion is about one-eighth, as for the whole stratified crust; and this would yield sufficient carbon dioxide to cause a pressure of 223.8 atmospheres.

It is not credible that such amounts of carbon dioxide have ever existed in the atmosphere at one time. During the larger part of the aeons of carbonate formation, animal life has existed in great abundance upon the earth; and this would have been impossible with 200 to 400 atmospheres of carbon dioxide present. As the proportion of this gas in the existing atmosphere is only 4½ parts in 10,000 by weight, 200 atmospheres of the gas would be 444,000 times the present proportion. It is scarcely more credible that the pressure of 200 to 400 atmospheres would have been compatible with either vegetable or animal organization, so similar as it was fundamentally to modern organization. As this large amount of carbon dioxide cannot be supposed derived from the earth's crust, it must have been derived from interplanetary space. This would imply an addition to the earth's mass of .0003806, which is about $\frac{1}{2636}$ part of the present mass.

2. *The kaolinization of felspars.* — Hunt has shown that the kaolinization of a layer of 51.66 metres of orthoclase, or its equivalent of quartzo-felspathic rocks, would result in 23.7 metres of kaoline, and would use up 10,333 kilograms of carbon dioxide per square metre of surface. This is the weight of the atmosphere. Now, the whole amount of felspathic decomposition during the sedimentary ages must much exceed 500 metres in vertical thickness of kaolinic deposits. But 500 metres of kaoline represent 21.1 atmospheres of carbon dioxide; and, assuming the mass of the atmosphere at $\frac{1}{1200000}$ in relation to the earth, the carbon dioxide fixed in the processes of kaolinization would be .0000175826 of the total mass of the earth.

3. *Decay of hornblende, pyroxene, and olivine.* — According to Hunt, the decay of 10⅓ metres of such minerals, or their equivalents in hornblendic and pyroxenic rocks, would yield carbon dioxide equal to 1 atmosphere: hence, if the earth's crystalline rocks have afforded 500 metres of hornblende and pyroxene, they must have fixed 48.387 atmospheres of carbon dioxide. This, in relation to the earth's mass, is 0000403209.

4. *Conversion of ferrous into ferric oxide.* As Ebelmen states, the conversion of 21,357 kilograms of ferrous oxide into 23,750 kilograms of ferric oxide would consume the whole of the 2,376 kilograms of oxygen in the atmosphere (more exactly, 1.007 atmospheres) covering a square metre. If, then, we suppose the existence over the earth of 1,000 metres of sediments derived from the decay of crystalline rocks containing only one per cent of ferrous oxide, weighing, according to Hunt, 25,000 kilograms, this is 1.052 times the amount requisite to fix the oxygen in 1.007 atmospheres; that is, 10 metres of ferric oxide represent the fixation of 1.059 atmospheres of

[1] See a memoir by T. Sterry Hunt in *Amer. journ. sc.*, May, 1880, where references are given to numerous other publications.

oxygen. This, in relation to the earth's mass, is .0000008825.

5. *Unoxidized carbon.* — This occurs not only in coal-beds, but in pyroschists and petroleum. We find that the oxidation of a layer of carbon 0.7123 metre in thickness would use up all the oxygen in the atmosphere. A layer 2.252 metres thick, and having a specific gravity of 1.25, if converted into carbon dioxide, would exert a pressure of one atmosphere. This would amount to 2,267,000 tons of 2,240 pounds each on a square mile. Mr. J. L. Mott calculates that the amount of unoxidized carbon per square mile cannot be less, and is probably many times greater, than 3,000,000 tons. If we adopt this determination, it will imply a depth of 0.982 metre, and the proportion of the earth's mass will be .00000036318. This is the amount of carbon dioxide which must be decomposed to yield a layer of carbon over the earth only a trifle over three feet in thickness, while it is probable that the carbonaceous deposits of the earth's crust exceed this. Now, it will hardly be maintained that the uncombined carbon of the earth's crust was derived from any other source than the atmosphere, and mostly through the agency of vegetation. The earth's atmosphere must therefore have contained all this amount of carbon dioxide. With the fixation of the carbon, the freed oxygen, it may be said, might have been employed, as far as it would go, in the formation of ferric oxide, whose demands upon the atmosphere have just been computed; but, as it would only satisfy $\frac{1}{309}$ of those demands, it is hardly necessary to consider the question.

6. *Meteoric contributions.* — If, as commonly assumed, 400,000,000 meteors enter our atmosphere daily, an average weight of ten grains each would amount to a yearly addition of 93,170 tons. This, in 100,000,000 years, would amount to .000000001542 of the earth's mass, and would form a film .292, or nearly $\frac{2}{7}$, of an inch thick, having a density of 2.5.[1]

Gathering together these various contributions to the earth's mass during 100,000,000 years, we have the following: —

1. CO_2 represented by the carbonates	.0003806
2. CO_2 fixed in kaolinization of felspars	.0000175826
3. CO_2 fixed in decay of hornblendic and augitic rocks	.0000403209
4. O fixed in conversion of ferrous oxide	.0000008825
5. CO_2 represented by uncombined carbon	.00000036318
6. Meteoric contributions	.000000001542
Aggregate	.000439750722

This is an addition of $\frac{1}{2416}$ to the earth's mass; and, in the present state of knowledge, it does not appear on what grounds assent can be withheld from the result, or some result of similar purport. It must be left with the astronomer to determine what relation this increase may sustain to the moon's acceleration in its orbit and to other phenomena. It may be noted, however, that the remote secular recession and retardation of the moon, which G. H. Darwin has recently brought to view, would have been delayed by the cause here considered, and the time required for the attainment of the moon's present relations would have been prolonged, but to what extent remains to be determined.

The evidences disclosed by these recent researches, of the slow accession of gaseous and solid matters to the earth, possess a profound interest. It would almost seem that the earth's atmosphere is only so much of the intercosmical mixture of gases and vapors as the earth's mass is capable of condensing around it, and that the proportions of these gases are determined separately, each by its own weight and elasticity and by its relative abundance in space; so that, as any one becomes diminished by fixation in the planetary crust, new supplies arrive to keep the ratio constant. As under this view it is apparent that an atmosphere should be accumulated around the moon, even after the saturation of the pores of its rocks, it may be said that the moon's mass and volume are such that her atmosphere would possess only $\frac{1}{36}$, or, according to Neison, $\frac{1}{50}$, the density of the earth's atmosphere; and this degree of tenuity might reduce the lunar atmospheric refraction to the small value actually observed.

ALEXANDER WINCHELL.

[1] The value given for this film in a note, p. 14, in my 'World-life,' should be multiplied by 365¼.

Regulation of electromotive force.

In one of the articles — the first, I think — recently published in SCIENCE (ii. 642) upon the subject of the electric light on the U. S. fish-commission steamer Albatross, the writer tells us that the brilliancy of the Edison incandescent lamps is kept constant, when other lamps upon the circuit are lighted or extinguished, by placing an adjustable resistance in the circuit of the field-magnets of the dynamo-electric machine, 'whereby the internal and external resistances are balanced.'

The importance of the subject scarcely seems to warrant any more space being devoted to it than already has been. But the point that I bring up is not an immaterial one, such as whether the engine is on the port or the starboard side of the vessel: it is a question which involves interesting and important physical principles.

The reason an adjustable resistance is required in the field-circuit of an Edison dynamo, in order to maintain a steady incandescence of the lamps, results from the fact that the armature has some resistance. This resistance is quite small, to be sure, but it has a considerable effect, nevertheless.

In order that a multiple arc system should be perfect, so that the dynamo or generator would require no adjustment or regulation when lamps were turned on or off the circuit, it would be necessary that this generator should have absolutely no resistance: for, if it were possible to reduce the internal resistance to zero, then there would be no fall of potential within the machine itself; that is, the fall of potential would all be in the external circuit, and the difference of potential between the poles of the generator would be equal to the total electromotive force of the circuit. In that case, all that is necessary is to keep the electromotive force constant; and then it follows, that any number of the lamps in the system may be lighted or put out without producing any fluctuation whatever in the light of the other lamps, because the incandescence of a given lamp depends only upon the electromotive force with which it is supplied. Now, we know that the electromotive force generated by a dynamo is constant, provided that the speed of rotation of its armature, and the intensity of the field-magnetism, are kept constant. The armature is maintained at a constant speed because it is driven by a steam-engine furnished with a governor, the function of which is to secure a constant speed;[1] and the field-magnets have a constant strength because the current which excites them is constant, since this current, like the current in the lamps, is produced by an electromotive force, which, by hypothesis, is constant.

Let us now consider the case where the resistance of the armature is not zero (to which, of course, it

[1] The speed would remain constant, but the *power* required would increase with the number of lamps in circuit.