Letters to the Editor.

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A Possible Explanation of the Behaviour of the Hydrogen Lines in Giant Stars.

WHILE the general behaviour of the absorption lines in stellar spectra has been well accounted for by thermodynamic theory, the Balmer series shows marked peculiarities. In spite of the very high resonance potential, these lines appear even in stars of class G, and their intensity is conspicuously affected by absolute magnitude—that is, by the density of the stellar atmosphere.

According to the elementary theory, the fraction of all the hydrogen atoms present which are in the two-quantum state (and hence ready to absorb the Balmer series) should be $f_2 = q_2 e^{-(\chi_1 - \chi_2)/kT}$, where k is Boltzmann's constant, $\chi_1 - \chi_2$ the resonance potential, and q_2 the weight of the two-quantum state[1]; and this fraction should be independent of the pressure. Introducing $\chi_1 - \chi_2 = 10{\cdot}16$ volts we find $f_2 = q_2 e^{-117000/T}$. For $T = 5000°$ (roughly corresponding to the outer atmosphere of the sun), $f_2 = 6 \times 10^{-11} . q_2$; for $T = 3000°$ (rather high for the corresponding region in an M-star), $f_2 = 8 \times 10^{-18} . q_2$; and even for $T = 10{,}000°$, $f_2 = 8 \times 10^{-6} . q_2$.

For comparison, we may take λ4481 of Mg+, for which $\chi_1 - \chi_2 = 8{\cdot}85$, and $f_2 = 1{\cdot}2 \times 10^{-9} . q_2$ if $T = 5000°$. Allowance for the fact that much of the magnesium in the sun is neutral may at most reduce f_2 to $10^{-10} . q_2$ of all the Mg atoms present. Now λ4481 and Hα are the strongest lines absorbed by atoms in the corresponding states; yet the former is barely visible in the solar spectrum, and the latter is one of the strongest lines of all. This would demand an absurdly great abundance of hydrogen relative to magnesium (itself an abundant element) if the effective values of q_2 were comparable. Moreover, in giant stars, and especially in super-giants, such as α Orionis and the Cepheid variables, the Balmer lines are very much stronger than in dwarf stars of the same general spectral class, though the temperatures of the latter are higher.

It appears necessary, therefore, to assume that the effective value of q_2 for the two-quantum state of hydrogen is increased, in some special way, by a very large factor, which increases as the pressure diminishes.

A tentative explanation may be found in the fact that one of the two two-quantum states of hydrogen is metastable. The state called 2_2 by Bohr (or $2p$ in the ordinary series notation) can pass to the normal $1_1(1s)$ state by emission of the resonance line λ1216; but an atom in the $2_1(2s)$ state can (so far as we know) get out of it only by the absorption of radiation, or else by a collision of the second kind with another atom or an electron. A similar condition is found in helium, where the 1σ state (the lowest in the doublet system) is metastable. There is direct evidence[2] that a helium atom may remain in this state for an average life of the order of 10^{-3} sec. or more, as against about 10^{-8} sec. for an excited atom which can get rid of its energy by radiation. The 2δ state for Mg+, concerned in the absorption of λ4481, is of the latter type.

If it may be assumed that the number of hydrogen atoms in the $2s$ state in a star's atmosphere, and hence the effective value of q_2, is greatly increased when the life of the metastable state is long, the peculiar behaviour of the Balmer lines becomes explicable. The increase in the concentration of absorbing atoms accounts for the strength of the lines; while collisions, which get the atoms back to normal and diminish this concentration, will be more frequent in the denser atmospheres of dwarf stars.

The average interval between collisions, in a gas of pressure p mm. and temperature T° K, between an atom of molecular weight m and radius r cm. and atoms of molecular weight m' and radius r' is

$$\frac{2{\cdot}24 \times 10^{-24}}{p(r+r')^2}\sqrt{\frac{mm'T}{m+m'}}.$$

For excited hydrogen atoms (for which $r = 2 \times 10^{-8}$ cm., $m = 1$) moving in a gas of temperature 5000° and pressure 0·1 mm. (roughly the conditions in the sun's reversing layer) the collision-interval comes out $1{\cdot}8 \times 10^{-4}$ sec. if the "other atoms" are ordinary hydrogen ($m = 1$, $r = 5 \times 10^{-9}$), and 9×10^{-6} sec. if they are electrons ($m = 1/1850$, $r = 0$). In a giant star, where the pressure is probably from ten to a hundred times less, these intervals would be correspondingly increased. They are evidently quite of the right order of magnitude to be dominant in determining the mean effective life of a metastable state such as has been observed in helium, and without influence on ordinary states.

The influence here suggested will be important only for atoms in metastable states of high energy content, which are more likely to lose energy than to gain it, even in collisions with other excited atoms.

We might therefore expect to find it for the familiar lines of helium. Here $\chi_1 = 24{\cdot}5$ and $\chi_2 = 4{\cdot}7$ for the 1σ state, so that f_2 should be $10^{-10} . q_2$ at 10,000° and $2 \times 10^{-7} . q_2$ at 15,000° (which is probably near the temperature at which the helium lines reach their greatest intensity). For λ4481, at 10,000°, $f_2 = 2{\cdot}8 \times 10^{-5} . q_2$. Here again the helium lines are stronger than might be expected from the probable abundance of the element (though the latter is hard to guess at). More definite evidence is found in supergiant stars like α Cygni, where the helium lines are present, though there is no trace of them in ordinary giants of Class A_2 or even A_0.

For the Pickering series of He+, $\chi_1 = 54{\cdot}2$, $\chi_2 = 3{\cdot}4$ and $f_2 = 6 \times 10^{-9} . q_2$ even at 30,000°, so that the argument from abundance would appear to be applicable.

The red triplet of oxygen, λ7772-75, for which the excitation potential is almost the same as for the Balmer series, should be strengthened in giant stars and Cepheids, and would be interesting to observe.

The great concentration of atoms in metastable states, which is here postulated, would not be expected to occur in a gas in thermodynamic equilibrium. Such concentrations have, however, often been observed experimentally in vacuum tubes, which are of course very far from being in such equilibrium. Whether the departure from equilibrium in stellar atmospheres, which undoubtedly exists, would permit a sufficient concentration to explain the observed facts in the manner here suggested may prove a problem of interest to theoretical investigators.

An observational test appears, however, to be possible. The supposed concentration affects only the $2s$ state of hydrogen, and not the $2p$ state. Of the three components of Hα, $2s - 3p$ is at 6564·516 (I.A.), $2p - 3s$ at 6564·658, and $2p - 3d$ at 6564·720. In the laboratory, the components of longer wavelength are the stronger. In the stars, that of shortest wave-length should, on our hypothesis, greatly predominate.

There is no hope of resolution of this group in the

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[1] Fowler and Milne, M.N., R.A.S., 83, 403, 1923.

[2] F. M. Kannenstine, *Ap. J.*, 55, 345, 1922.

stars, and measurement of the mean wave-length of the blend is greatly complicated by the effects of radial velocity, and of the "K term." The latter unfortunately indicates a shift in the opposite direction.

Even in the sun, radial velocity may greatly complicate the investigation. Could the $H\alpha$ line be observed double in the prominences—or show to appear single when a pair of separation 0·15 Å would certainly be resolved—the question might be settled.

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June 21.

Leaf-mould.

It must be a matter of common knowledge to persons interested in woodlands that some woods and copses have a more or less thick deposit of leaf-mould, whilst in others this covering is absent. It is not a question of the presence or absence of particular trees, *e.g.* oak or beech, and it often happens that within the limits of a single wood considerable differences exist, in respect of leaf-mould formation, in different parts of it.

I have noticed that its presence or absence is very commonly correlated with the character of the surface soil. Sand or gravel promotes, whilst heavy, and especially calcareous, soils seem to inhibit its formation. In a small wood that I have had under observation for a number of years the surface varies from chalk to heavy clay, with a good deal of intermediate calcareous loam. Leaf-mould never forms naturally in this wood, although the conditions would seem to be generally favourable. The trees are reasonably thick, consisting mainly of beech and some oak. The ground is well drained and dry for the most part, whilst in other spots it is damp and even boggy. There are large hollows where leaves collect, and from which the winds never move them, even in winter. But no real leaf-mould ever forms. The mass of dead leaves and twigs rot down and evaporate, so to speak, next year. This is to be attributed to bacterial action, and I believe that for the most part the result is due to the bacteria being able to carry on the disintegration process, mainly to carbon dioxide and water, in the presence of the available calcium carbonate of the surface soil. In another wood near by there are deposits of sand and gravel overlying the loams and chalk, and there the abundance of leaf-mould is very striking.

It occurred to me that the presence of the "acid" silicious top soil might be the decisive factor in the situation. Such an acid soil, by not neutralising the products of bacterial action, would conduce to the arrest of bacterial activity and so might provide in the first-named wood the requisite condition for leaf-mould formation which had, up to that time, been lacking. This hypothesis received confirmation. A covering of sandy gravel spread over the surface of one of the hollows was followed by the formation of an excellent leaf-mould, though this had not occurred in this hollow before, nor did it take place at all in those hollows adjacent to it which had not received a coat of gravel.

I do not suppose that the whole story of leaf-mould formation is contained in the foregoing, and it may well be that in other situations additional or other factors are concerned. Indeed it seems certain that soil drainage also influences the process, perhaps through its affecting conditions of suitable aeration. At any rate it happens that when pans of clay occur near the surface of a gravel or sandy soil in woods, with the result that the ground is water-logged for a part of the year—in such places one looks in vain for leaf-mould, though a black peaty deposit may occur in its place. These peaty deposits are very different from genuine leaf-mould, though both owe their origin to the disintegration of vegetable matter.

Leaf-mould, regarded from the point of view of the succession of organisms that are concerned in its production, and of the complex chemical changes therein involved, offers an attractive field for research. It is perhaps scarcely necessary to emphasise the fact that in addition to problems of more purely scientific interest, there are others connected with it which are of industrial importance as well.

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The Theory of Hearing.

Referring to Prof. Scripture's letter in Nature, June 28, the following observations on the vowel response of piano strings, which differ from those described, may be worth recording.

Using a small Broadwood upright piano with the lid open, and singing or speaking well into the instrument, I have found, (1) That a recognisable vowel response is given to *all* the English vowel sounds, though those to *i* (as in eat) and I (as in it) are relatively faint, owing to the poor response of the strings to frequencies of 2000 and more.

(2) That the response *is* given almost equally well, whether the vowels be intoned as prolonged or as relatively instantaneous sounds.

(3) That quite a good response is given to vowels sung "portamento" (with a variation of pitch of about an octave) or spoken as short sounds of varying laryngeal pitch. In some cases, especially in that of *u* (who), the "portamento" response is quite as good as that for the same vowel when intoned at constant pitch.

Experiment shows that a vibrating rubber strip "larynx," attached to a double resonator, will produce a constant vowel sound while the frequency of the larynx note is varied over an octave or more, by variation of the air pressure supplied to the larynx.

It seems reasonable to suppose that, in the production of a "portamento" vowel sound in the human mouth, the same thing applies—*i.e.* that the resonance frequencies of the vocal cavity remain substantially constant, though the frequency of the laryngeal puffs which evoke them is progressively changing.

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In reply to Prof. Scripture's letter in Nature of June 28, I am not able to discuss the more recondite points he raises as to the nature of vowel sounds, or the mathematical formulæ by which alone, as he states, they can be subjected to analysis. I cannot, however, accept his statement that the undamped piano strings fail to respond to short spoken vowels. The facts can be tested in a moment by any one who has access to a piano. The fuller the tone of the instrument the clearer will be the response.

My own observation is that one gets a recognisable and distinguishable vowel however short the utterance, and that the quality of the resonated vowel is not noticeably changed by shortening or lengthening the vocalisation of the vowel sound; and further, that the characteristics of the vowels are as clearly distinguishable in the sharply uttered as in the sung vowel: ă, ā, i, oe, oo, all seem to come out fairly clearly and distinguishably. As Helmholtz says, the