19. THE STATIONARY H- AND K- LINES OF CALCIUM IN STELLAR ATMOSPHERES

(*Nature*, **107**, 498, 1921)

It has been noticed by many observers that the space surrounding early B-classes of stars (*e.g.* δ Orionis) often show absorption of H- and K-lines of calcium, which do not share in the Döppler displacements of the other absorption-lines of the stellar spectra. This suggests that these stars are enveloped in an atmosphere of calcium vapour which does not partake in the orbital motion of the stars (NATURE, April 21, p. 247.)

There is, of course, naturally a difficulty in realising why calcium, alone of all elements, should be found to occur in the attenuated atmospheres surrounding a stellar system. Very closely connected with this phenomenon is the observational fact that in the flash-spectrum of the sun the longest arcs are those corresponding to calcium H- and K-lines, indicating that in the sun also the outermost layers (according to Mitchell, 14,000 km. above the solar disc) are composed of calcium. Hydrogen, the lightest of elements, which we should expect to occur in the highest layers, disappears at a much lower level (8000 km., according to Mitchell).

The problem is naturally a complicated one, but I think that a way to solution is afforded by the theories of selective radiation-pressure and of the temperature-ionisation of gases advanced by me in the following papers:—"On Radiation Pressure and the Quantum Theory" (*Astrophysical Journal*, September, 1919); "On Selective Radiation Pressure, etc." (Journ. Coll. of Science, Calcutta, 1920); "Ionisation in the Solar Chromosphere, etc." (*Phil. Mag.*, vol. xl., 1920); and "On a Physical Theory of Stellar Spectra" (Proc. Roy. Soc. Lond,. May, 1921).

According to these papers, the H- and K-lines are the resonance-lines of Ca^+, *i.e.* of a calcium-atom which has lost one electron. The resonance-line of neutral calcium is the *g*-line, $\lambda=4227$. In the Fraunhofer spectrum we get H, K, and *g*, showing that in the solar photosphere calcium is largely ionised owing to the high temperature prevailing there. At higher levels, owing to diminution in concentration, the ionisation becomes complete, so that the *g*-line disappears entirely, leaving only the H- and K-lines.

The sun is a dwarf star of the Go class, corresponding to a surface temperature of 7000-7500° K. When we consider the spectra of the still hotter stars, classes F, A, and B, we find that the *g*-line becomes fainter and fainter, until it disappears altogether from the B8A class. In the still hotter stars we have only the H- and K-lines, showing that they do not contain neutral calcium at all, but only ionised calcium.

This explains the varying behaviour of the *g*-line and of the H- and K-lines, but we have still to determine the force which drives Ca^+ to the outermost layers. It is natural to conclude that the forces which are responsible for driving calcium absorbing H and K to the greatest height in the solar atmosphere are also responsible, in the case of stars having a larger surface temperature, for driving calcium to the surrounding parts of space. Now what can this force be, and why should this show a preference for calcium?

In the case of the sun I have attempted to show that this force is furnished by the pressure of radiant energy from the solar disc acting in a selective way upon the Ca^+-atoms. The term "selective" is most important here and requires an explanation. Radiation-pressure is due to absorption, and therefore, in the case of a gas illuminated by white light, only those pulses which the gaseous atom is capable of *most frequently absorbing* are effective in producing pressure. A gas can usually absorb lines of the principal series alone, but the lines of the subordinate series are absorbed only in exceptional circumstances, and even then to a much smaller extent; so that the maximum lifting effect of radiation-pressure is to be expected only in the case of atoms absorbing the resonance-lines. (For more detailed arguments see the papers above-mentioned). In addition to this, the lifting force would depend on the intensity of the region corresponding to the absorbed lines in the spectrum of the continuous background of white light, and on the solid angle subtended at the atom by this background.

In the case of the sun the surface temperature is 7300-7500°K (Biscoe, *Astrophysical Journal*, vol. xlvi., p 355), so that, according to Wien's law, $\lambda_m T=b$, the maximum of emission lies at $\lambda=3920$ Å.U., very close to the H- and K-lines of Ca^+. Also these lines are the resonance-lines of Ca^+, so that we have here the maximum effect of selective radiation-pressure. The resonance-line of hydrogen is at $\lambda=1216$ Å.U., and therefore the effect of radiation-pressure is extremely small.

It is not possible to say whether the lifting power of selective radiation-pressure alone is capable of neutralising the force due to the gravitational attraction of the sun, but it looks very much as if this were so. Without being dogmatic on this point, we can work out the consequences of this assumption. In the case of stars having a much larger surface temperature, say 14,000°K, B8A class, the value $E\lambda$ for H- and K-light would be much larger, so that the radiation-pressure is still greater, and in some cases preponderates over the greater value of gravitational force on these stars. Thus Ca^+-atoms would be driven very far into the surrounding space. They will be prevented from absolutely leaving the system, because with increase of distance the solid angle subtended by the disc of the star at the atom would diminish, and a condition of equilibrium would at last be reached.

The same phenomenon occurs to a smaller extent, in the case of the sun, with Sr^+ and Ba^+, which have their resonance-lines near the spectral region of maximum intensity, but owing to their greater atomic weight the compensation is not so marked. Still Sr^+ is very prominent in the chromospheric spectrum, rising to a height of 6000 km.

The question may be asked: Why do we not obtain the same phenomenon in the case of the other light elements ? These can be divided into two broad groups: (1) non-metals like H, He, N, O, Ne, and A, having a high ionisation-potential, of which the resonance-lines lie in the extreme ultra-violet—*e.g.* for H, at $\lambda=1216$ Å.U., for He, at $\lambda=585$ Å.U. (Lyman and Fricke, *Phil. Mag.*, May, 1920)—and can be detected only by subordinate lines—for helium, by D_3, $2p—md$; for hydrogen, by the Balmer lines. Naturally the effect of selective radiation-pressure is small on these elements. (2) Elements like Na, K, Mg, Al, Sc, Ti, Fe, which have an ionisation-potential varying from 5 to 8 volts. Under the conditions treated here these are mostly ionised, but the resonance-lines of these ionised elements lie mostly outside the region available for observation, *e.g.* the resonance-lines of Mg^+ are $\lambda=2795{\cdot}5$, $2802{\cdot}7$. The resonance-lines of Na^+ and K^+ have not yet been discovered, and probably lie in the extreme ultra-violet. Sc^+ and Ti^+ are represented by prominent lines in the chromospheric spectrum, but it is not yet known whether these are resonance-lines of these elements.

The hypotheses thus appear to be promising, but nothing final can be said before we can calculate the absolute value of the selective radiation-pressure on an atom. According to Eddington (Monthly Notices, R.A.S., 1920, vol. lxxx., p. 723), the absolute value of the radiation-pressure is too small to account for the total neutralisation of gravitational force on the sun; but in that paper the consequences are worked on the basis of the continuous theory of light. The foregoing line of investigation at least brings out the intimate connection between the stationary character of the H- and K-lines in the space round the stars and the great prominence of these lines in the chromospheric spectrum. It shows that the higher chromospheric levels, as well as the space round B- and A-stars, may probably contain, besides Ca^+, also Na^+, K^+, Sc^+, Ti^+, and Mg^+, but owing to the fact that our observations have to be limited between $\lambda=3000$ Å.U. and 6000 Å.U., and that none but the resonance-lines of Ca^+ lie within this region, we can detect nothing but Ca^+. But if some day we can overcome the limitation imposed by atmospheric absorption, probably we shall be able to detect Li^+, Na^+, Mg^+, K^+ in the atmospheres surrounding B-stars which show stationary H- and K-lines.

Berlin, May 8.

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20. ON THE IONISATION OF GASES BY HEAT

M. N. Saha and Paul Gunther

(*Jour. Dept. Sci.*, Cal. Univ., **4**, 97, 1922)

§ 1. Introduction

It is well known that a column of gas, which is subjected neither to ultraviolet light, Röntgen light, or any other familiar ionising agent, possesses no electrical conductivity. Beginning from Hittorf[1] many investigators have performed experiments to see, if by simple heating, gases can be made to conduct electricity. As the following review will show, most of these experiments were indecisive.

In the light of modern theories of atomic structure, the problem reduces to the knocking out of the outermost electron, or electrons, from the atomic system by the mutual collisions of atoms. The problem is thus analogous to the emission of electrons from incandescent solids and liquids. In this connection, it is well worth quoting the following passage from Richardson's "The Emission of Electricity from Hot Bodies, p. 298."

"There is no satisfactory *a priori* reason for expecting emission of ions at a high temperature to be confined to the matters in solid or liquid states. It is however to be