Letters to the Editor.

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Liquid Stars.

IN NATURE of Feb. 4 (p. 173), Dr. Jeans has given an attractive exposition of his new theory of stellar evolution involving 'liquid' stars. With all goodwill towards innovations which might help to remove present difficulties of the evolutionary theory, I cannot follow Dr. Jeans's lead because I find myself in disagreement with him on two preliminary and essential points. These points, discussed separately below, have already been the subject of careful investigation, and even in Dr. Jeans's fuller papers on his theory I find no new considerations which would modify the conclusions formed.

(1) STATE OF HIGHLY IONISED MATERIAL.—The theory put forward in 1924 that stellar material is a nearly perfect gas up to densities exceeding those of terrestrial solids met with surprisingly little opposition at the time; but opposition has now come in the form of Jeans's liquid stars. Fortunately, he and I are agreed as to the extent of the ionisation. In the upper half of the main series the ions are chiefly nuclei attended by two K electrons—a structure having a radius of about 10^{-10} cm. The average distance between neighbouring ions is at least 100 times greater. Jeans assumes heavier ions than I do, but that only augments the disparity between size and separation. The hypothesis of liquid stars postulates that in this condition the ions are jammed; that is to say, their effective volumes are 100,000 times greater than the volume covered by the electron system, and the space apparently so empty is in reality packed full. The defence is (*Mon. Not. R.A.S.*, **88**, p. 736): "Even with neutral helium the effective diameter of the atoms in the liquid state is 7·4 times that of the electron orbits as calculated from Bohr's theory. No one can say what it would be if the temperature were raised from two or three degrees absolute to ten or a hundred million degrees absolute, and we might, in any case, expect atoms surrounded by a powerful electric field to have relatively larger effective diameters than neutral atoms such as that of helium." The last defence is certainly wrong. The effect of the electric fields has been investigated by Debye and Hückel, Kramers, and (with more specific reference to stellar conditions) by Rosseland, Fowler, and myself. It is not necessary to read far into these investigations to see that the electric fields make the gas super-perfect and have the opposite effect to that which Jeans expects. His first defence is an *ad hoc* postulate that at high temperatures something unknown to present-day physics intervenes to give the ions what is apparently an impossibly large volume. All the evidence is that the volume diminishes with increasing temperature. Moreover, I understand that atomic volume is now generally regarded as conditioned by Pauli's exclusion principle, and I cannot think that physicists will easily be persuaded to admit the enormously extended sphere of exclusion demanded by Jeans.

Dr. Jeans's reference to atomic volume is so brief and perfunctory that I think I am not misrepresenting him in saying that he adopts liquid stars, not on grounds of physical plausibility, but for reasons somewhat as follows. He has persuaded himself that a gaseous star is necessarily unstable. Therefore a star in any one of the long-enduring stages *cannot* be gaseous; and if present-day atomic physics declares it to be gaseous, then so much the worse the present-day atomic physics. This is logical enough if we grant his premises—which I do not.

(2) THERMODYNAMIC INSTABILITY.—Any inclination I may have had to discuss Dr. Jeans's earlier theories of evolution was arrested at the start by disagreement as to stability; he made out to be stable the stars which I (following Russell) found unstable, and vice versa. He has now come into line with Russell and myself in agreeing that if the rate of liberation of subatomic energy E decreases as a consequence of compression the star is unstable. In the other direction agreement is still not complete. I have maintained that if E increases moderately with compression the star is stable, but too rapid a rate of increase will throw it into pulsation. Jeans does not disagree with this for the smaller stars, but he claims to have shown that for stars of mass greater than $2 \times$ sun the range of stability disappears. The cause of this divergence is pointed out by H. Vogt in the current issue of the *Astronomische Nachrichten* (No. 5545), who shows that Jeans has omitted a term in his equations, and when the term is included the range of stability does not disappear. The range of stability is, however, rather narrow, and I have long urged the consequent difficulties (NATURE, Mar. 21, 1925; May 1, 1926) which seemed to be passed over too lightly in Jeans's earlier theories of stellar evolution. I have pointed out that the range is widened indefinitely if the liberation of energy is a two-stage process with a time-lag between the formation of the active substances and their spontaneous disintegration. At present this seems the most plausible way out of the difficulty. In any case it scarcely calls for the desperate remedy of liquid stars.

With regard to the evolutionary part of his theory, I am puzzled to find these 'liquid' stars behaving very differently from the way we supposed them to do when last I (like others) believed in them five years ago. Then the effect of loss of energy and contraction was that the liquid core increased in size and diminished in temperature. This still seems to be the correct deduction. But it would rule out the increase of central temperature, with consequent jumps to states of higher ionisation, on which Jeans relies.

In refusing to follow Jeans into the fire, I do not wish to give the impression that the situation is entirely comfortable in the frying-pan. Besides numerous difficulties associated with sub-atomic energy, there is the discrepancy of a factor 10 or more which I found between the stellar absorption coefficient and the value derivable from Kramers' theory of electron capture. Although Jeans alludes to this as one of the difficulties of the gas theory, I am not sure from his discussion whether the liquidity of the stars is supposed to cure it or whether he adheres to his former view that the discrepancy is removed by assuming very heavy elements in the stellar interior. The latter possibility was examined when the discordance was discovered, and it appeared that there was little or no advantage in substituting heavy elements (*Monthly Notices*, **84**, p. 110; "The Internal Constitution of the Stars," § 168). If, on the other hand, he explains the discrepancy by liquidity, so that the perfect gas curves for giants run $2\frac{1}{2}$ magnitudes above those shown in his diagram, I can only feel the more amazed at the prodigous size of his ions which in M type stars must be supposed to jam at densities $\frac{1}{100}$ that of air.

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Observatory, Cambridge,
Feb. 12.

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