it would need nothing more to imbue the whole pen with the idea that there was some cause for fear. Then they would all make a rush, and their terror and the momentarily recurring incentives to, and aggravations of, it in the shape of collisions would only subside when the sheep had broken out and were in the open, clear of one another and of their troughs and hurdles.

If this is the explanation of the panic, then it is easy to understand why folded sheep are so much more likely to suffer than those lying in open fields.

The heavy, oppressive atmosphere accompanying the thick darkness, the susceptibility of sheep to atmospheric disturbance, and their nervous and timid dispositions would all tend to increase the fright the sheep experienced. The cause of the panic being a cloud rolling along so low down as (apparently) to touch the ground, the tops of the hills and the high-lying ground would naturally be most affected; and this is observed to be the case, although locally the usual direction followed by thunderstorms has indicated a line along which sheep stampeded on nearly every farm.

The Work and Discoveries of Joule.¹

By SIR DUGALD CLERK, K.B.E., F.R.S.

THE greatest generalisation in the early history of physical science was made late in the seventeenth century by Sir Isaac Newton when he enunciated the laws of motion and deduced from them the existence in space of attraction between planets and the sun. Mechanical science has been built up on Newton's fundamental propositions and discoveries. The discovery by Joule in the middle of the nineteenth century of the mechanical equivalent of heat and his suggestion and determination of the existence of an absolute zero, together with the adaptation of Carnot's cycle of 1824 to the theory of heat as a mode of motion, provide generalisations of equal importance to Newton's law of gravitation, and from them fundamental thermodynamic laws are deduced: the equivalence of energy in different forms, conservation of energy and dissipation of energy. Joule's discovery, in fact, called the modern science of thermodynamics into existence.

Manchester has been the home of many highly distinguished men—great scientific men, great inventors, and great masters of industry and business—but it is fortunate indeed in its connection with two of the greatest discoverers in the history of the world, Dalton and Joule. Joule read his first paper before the Manchester Literary and Philosophical Society in the year 1841 upon the subject of "The Electric Origin of the Heat of Combustion." He contributed a long series of papers from that year until 1879, a period of thirty-eight years, and he dealt with a great variety of subjects, including experimental investigations on the phenomena of the voltaic current, the determination of the specific heat of bodies, heat and constitution of elastic fluids, mirage, freezing point of thermometers, galvanometers, dip circle, solar photographs, duty of electro-magnetic engines, magnetic storms, polarisation of platinum plates, mercurial air-pumps, and telescopic oscillations.

The debt of the practical engineer to Joule and his great associates is very real, but the science of thermodynamics did not supply the fundamental laws from which heat-engines were invented and developed. The steam-engine had been developed by Newcomen, Smeaton, and James Watt long before the birth of the science of thermodynamics. What is true of the steam-engine is true also of the hot-air engine and the internal-combustion engine; all the known types of heat-engine at present in use were invented before the year 1850, and practical experimental examples of both hot-air and internal-combustion engines were then in operative existence. Thermodynamics supplied the laws of the conversion of heat into mechanical work by which these engines are governed; it explained the relative perfection of engines already in existence, but it did not create these engines. It performed the very important service of dispelling the errors of thought which hindered the future advance of heat-engines. Such errors as to the theory of the regenerator and the theory of compression and expansion in all steam and internal-combustion engines, held by the most eminent engineers and scientific men so late as from 1845 to 1853, were rendered impossible by the splendid work of Joule, Kelvin, Rankine, and their Continental colleagues. The knowledge of thermodynamics has thus an increasing effect upon instructed engineers of the present generation. It is quite obvious that although the origin of heat-engines cannot be ascribed to Joule's work, yet the improvement and final development towards a maximum conversion of heat into mechanical work are rendered possible to the engineer of to-day by his great discoveries. Engineers and engine-designers are most grateful to Joule, and look back on his achievements as those of the utmost intellectual and practical importance.

Giant and Dwarf Stars.²

THE amount of light received from a star determines its *apparent magnitude* (m), the ratio for two stars differing by one magnitude being 2.512. The *absolute magnitude* (M) is what the apparent magnitude would be if the star were at the standard distance of 10 parsecs, which corresponds to a parallax of 0.1". If π is the parallax of a star in seconds of arc,

$$M = m + 5 + 5 \log \pi.$$

¹ Abstract of the first Joule Memorial Lecture delivered on Tuesday, December 14, 1920, to the Manchester Literary and Philosophical Society.

² Abstract of a lecture delivered before the Royal Society of Victoria, Melbourne, on October 14, 1920, by Dr. J. M. Baldwin, Government Astronomer.

In this equation m is not difficult to measure, and hence if π or M is determined the other can be found.

Russell took all stars for which fairly accurate values of π were available, and from the above equation computed M . Then, plotting M as ordinate and type of spectrum as abscissa, he found that (1) all white stars are far brighter than the sun; (2) range of brightness increases with redness; (3) all faint stars are red; and (4) all red stars are very bright or very faint.

Adams and Kohlschütter found that the relative intensity of selected lines in the spectrum of a star depended on the absolute magnitude from measurements on the spectrum. M being determined, the