130,000 light-years; 3·9′, 65,000 L.Y.; 7·7′, 43,000 L.Y.; 12·4′, 33,000 L.Y.; 20′, 26,000 L.Y.

These methods have been applied to finding the distances of sixty-nine globular clusters. The nearest are ω Centauri and 47 Tucanæ, 23,000 L.Y.; the average distance is 75,000 L.Y.; seventeen clusters are more distant than 100,000 L.Y.; the most distant is N.G.C. 7006, some 200,000 L.Y. (more than a trillion miles, using the British system of numeration).

The distribution in galactic longitude is curious. There are none between 45° and 190°, while more than half are between 300° and 350°. In latitude there are maxima on each side of the galaxy, with a gap in the galactic plane itself. The system forms a split ellipsoid with longest diameter some 300,000 L.Y., and distance of centre 65,000 L.Y. The co-ordinates of the centre are R.A. 17h. 30m., S. decl. 30°. While lying outside the galactic limits, the distribution of the clusters indicates that they form part of the same cosmic unit as the galaxy. Some preliminary investigations of their radial velocities by Prof. Slipher indicate that these are high, but smaller than those of the spiral nebulæ.

A. C. D. CROMMELIN.

FROST IN THE UNITED STATES.

IN a paper with the above title presented before the second Pan-American Scientific Congress at Washington (Washington: Government Printing Office, 1917) Mr. William Gardner Reed discusses the damage by frost in the United States. Following the rule of the Weather Bureau, he classifies frosts as "light," "heavy," and "killing," but he determines the dates of the last killing frost in spring and the earliest in autumn from the records of temperature, and not from the reports of damage. This is fully justified by the fact that the observations of temperature are continuous and exact, whereas the damage depends on many conditions.

The number of observations at any one individual station is seldom sufficient to show the precise chance of frost after a given date at that particular station, but if the observations at neighbouring stations are utilised, a sort of general mean date for the last frost in a district can be obtained. Working on these lines, Mr. Reed gives maps of the United States with lines showing the limits for killing frosts at various dates, the consecutive lines showing differences of ten days in the date. Thus the date for a line running close to the Gulf of Mexico is March 1, but for a line near the Canadian boundary it is as late as May 21.

The mean date of the last or earliest frost is not of much importance to the cultivator; he wants to know the date beyond which he will be reasonably safe from damage. For this purpose Mr. Reed calculates the standard deviation of the date, and since he finds that the distribution follows the normal curve, he is thus able to give the date beyond which a killing frost is not likely to occur more than once in ten years. This is, no doubt, a much more trustworthy method than using the extreme dates at each separate station. Charts are prepared in a similar way for the first killing frost in autumn; near the Canadian boundary the date is as early as September 1, but delayed until November 1 near the Gulf Coast.

The meteorological conditions that favour frost are not quite the same over the different States, though they are, in general, the clear skies of an anticyclone with their local nocturnal cooling. As a rule, east of the Rocky Mountains the frost area is south-east, and somewhat in advance of the anticyclone. In California north-easterly and easterly winds prevail for twenty-four or thirty-six hours beforehand, and a frost occurs if a clear sky accompanies the dropping of the wind.

Mr. Reed also discusses the cause why plants are damaged by frost, and arrives at the conclusion that the matter is far from being well understood. It is a very common belief that the damage is not so serious if the rise of temperature is slow, but Mr. Reed says that recently accumulated evidence throws some doubt upon this. He appears to hold that the length of time during which the trees are exposed to the cold is of importance, and that even if the heating of an orchard has been delayed until after the critical temperature is reached, there may still be time to save the fruit; and he concludes this part of his subject by saying that "evidently much more investigation is needed concerning the nature of frost effects within the plant."

CONSTRUCTION FOR AN APPROXIMATE QUADRATURE OF THE CIRCLE.

THE issue of the *Comptes rendus* of the Paris Academy of Sciences for March 25 last contains a paper by M. de Pulligny on a simple geometrical representation of the approximations to the numerical value of π given by Archimedes and Metius. Other approximations can be represented in the same way.

The construction is as follows:—Let OA and OB be two radii of a circle at right angles to one another. Let S be the mid-point of OA. Draw through S a line cutting the circle in P and Q, and OB (produced if necessary) in R. Let $OA=a$, $OR=ya$, $PQ=u$. Then we have $u^2=\{4-4y^2/(1+4y^2)\}a^2=$(say) ma^2. As PQ rotates round S, y varies continuously from 0 to ∞, and m from 4 to 3. When $y=0$, the square on PQ is greater than the area of the circle; when $y=\infty$, it is less: thus, in intermediate positions of the chord, the square on PQ gives an approximate quadrature of the circle, and m gives an approximate value of π.

The point R determines the chord PQ. If on AO produced we take a point I so that $4.AI=5a$, and if with I as centre and IA as radius we draw a circle cutting OB produced in R, we have $y^2=3/2$, and $m=22/7$, the higher limit given by Archimedes.

If on AO produced we take a point J so that $8.OJ=a\sqrt{3}$ (a result for which a geometrical construction can be easily given), and if with J as centre and IA as radius we draw a circle cutting OB produced in R, we have $y^2=(6+1/16)/4$, and $m=355/113$, the approximation given by Metius.

It will be noticed that there is nothing in this construction to enable us to fix the limits within which we must choose R to get a close approximation; but corresponding with any assigned value of m, and therefore of y, it gives a geometrical construction for the side of the square thus determined.

W. W. ROUSE BALL.

RADIATION AND THE ELECTRON.[1]

RECENT developments in the domain of radiation are of extraordinary interest and suggestiveness, but they lead into regions in which the physicist sees as yet but dimly—indeed, even more dimly than he thought he saw twenty years ago.

But while the beauty of a problem solved excites the admiration and yields a certain sort of satisfaction, it is, after all, the unsolved problem, the quest of the unknown, the struggle for the unattained, which is of universal and most thrilling interest. I make no

[1] Address to the Section of Physics and Chemistry of the Franklin Institute, Philadelphia, on January 4, 1917, by Prof. R. A. Millikan, professor of physics in the University of Chicago. The substance of this lecture has since been incorporated into a book recently issued by the University of Chicago Press, entitled "The Electron."