

present stable atoms have been formed in long periods of development out of the original bulk of protons, the remainder of which appears in the spectra of the A-type stars, the prominences on the sun, and the water on earth, the basic matter of all organisms, including ourselves—without water, no protoplasm and no life would have been possible. This means that in those cosmic furnaces—the central parts deep in the stars—the entire world was, and still is, fabricated, the materials constituting its matter as well as the radiations constituting its life. It is this life which appears, greatly weakened, at the hot stellar surfaces and, again a thousand times weakened, transformed into the life-energy of living beings.

Another difficulty arises: to penetrate into the heavier nuclei, hence to build the heavier atoms, theory may demand still greater densities and greater velocities of the protons, corresponding to still higher temperatures of hundreds or thousands of millions of degrees; these we do not find even in the stellar interiors. Can the heaviest nuclei, of uranium, of lead, of gold, perhaps have been present as original matter in the world? What, then, does the word 'original' mean here? Or shall we assume that the required conditions once existed in the past and now have disappeared—so that the heavy atoms are remainders, a kind of archaeological remains from conditions long passed? It may be plausible to connect the needed high temperatures with the original condition of closely packed galaxies and stars 2,000 million years ago. But all such ideas are a hesitant groping in a dark past.

So here, too, is an endless field of new problems to be cleared, where only the first sods have been cut. Here also we are working with millions, not for distances now and dimensions, but for intensities of energy. Here our path leads not towards the infinitely large, to study the great structure of the universe, but towards the infinitely small, to study the finest structure of nature, of what in the coarse-grained world of the senses is called 'matter' and 'radiation'.

And again this must be accomplished by a combination of sciences, of theoretical physics and abstract mathematics, tested by observation of matter and the radiation of various celestial bodies. Here, too, astronomy takes part in the elucidation of the essence of the world.

APPENDIX A

ARISTARCHUS' DERIVATION OF THE SUN'S DISTANCE

Aristarchus' seventh proposition is the most important, since it is there that the essential numerical result is derived. The demonstration is interesting enough, in its value to future astronomy, to reproduce it here in brief. In the figure A represents the position of the sun, B of the earth, C of the moon when seen halved. Hence angle $EBC = \text{angle } BAC = 3^\circ$. Let the angle $FBE (= 45^\circ)$ be bisected by BG. Since the ratio of a great and a small tangent to a circle is greater than the ratio of the underlying arcs and angles, the ratio GE to HE will be greater than the ratio of $\frac{1}{2}$ to $\frac{1}{8}$ of a right angle; i.e. greater than $15/2$. Furthermore $FG : GE = BF : BE = \sqrt{2}$, greater than $7/5$; hence FE/GE is greater than $12/5$. Combining it with the first inequality, we find the ratio of FE to HE greater than $15/2 \times 12/5 = 18$; and the ratio AB/BC which is equal to BH/HE, hence a little bit larger than BE/HE is

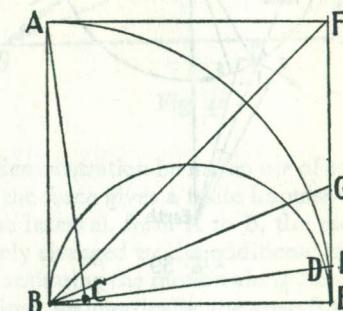


Fig. 38

present stable strains have been formed in long periods of development out of the original bulk of strains, the remainder of which appears in the species of the A-type.

APPENDIX B

APOLLONIUS' DERIVATION OF THE PLANETS' STATIONS

The computation of the stations of the planets in the epicycle theory was reduced by Apollonius to the geometrical problem of drawing a line intersecting the epicycle in such a way that the sections have a definite ratio. Through the revolution of the entire epicycle towards the left side the planet situated on its circumference moves from point 1 to point 2 over a distance

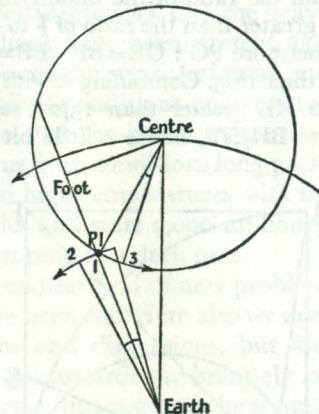


Fig. 39

equal to the angular velocity of this revolution times the distance earth – planet. At the same time the planet on its epicycle moves toward the right side, from point 1 to point 3 over a distance equal to the angular velocity on the epicycle times the radius of the epicycle. The latter displacement from the earth is seen foreshortened in the same ratio as exists between the distances planet – footpoint of the perpendicular and centre – planet. The planet seems to be at rest when the two displacements are seen from the earth to compensate. This will happen when the two distances planet – footpoint and planet – earth have the inverse ratio of the angular velocities. Or in other words: the planet has a station when the distance earth – planet and half the chord in the epicycle have the same ratio as the period of revolution and the synodic period.

APPENDIX C

NEWTON'S DEMONSTRATION OF THE LAW OF AREAS

In his Proposition I Newton derives Kepler's Law of Areas from the supposition that a revolving body is subject to a centripetal force directed to a

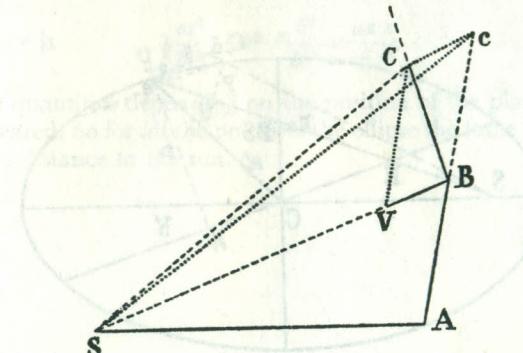


Fig. 40

fixed point. For the demonstration he makes use of equal finite time intervals, after each of which the force gives a finite impulse to the body towards the centre S. During one interval, from A to B, the motion remains the same; then at B it is suddenly changed by the additional motion BV. In the second interval, instead of continuing the motion along $Bc = AB$ the body follows the resulting path BC. Since, geometrically, the areas SAB and SBc are equal and because the impulse BV is directed toward S, the areas SBc and SBC are equal, the area SBC is equal to SAB . This holds for every further interval; every next triangular area is equal to the preceding one. So all the triangular areas described in equal time intervals are equal, and they will lie all in the same place. This holds also when the time intervals are taken ever smaller and their number ever greater in the same rate. Then, finally, we have a continuously acting force and a curved orbit, for which the areas described are proportional to the time used.

APPENDIX D

NEWTON'S DERIVATION OF THE FORCE OF ATTRACTION

In his Proposition XI (Cajori, p. 56), for the case of an elliptical orbit, Newton derives the centripetal force from Kepler's laws. In the figure of the orbit, where the lines are indicated by small letters, the planet is at P and the

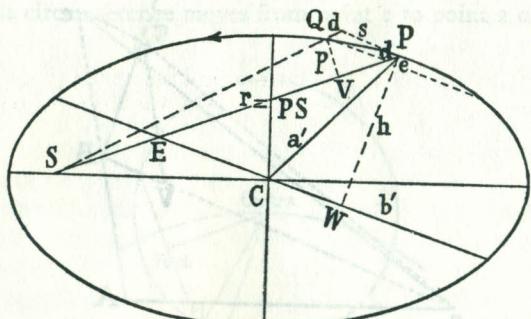


Fig. 41

sun occupies the focus S. The small deviation of the planet's motion from the tangent towards the focus is denoted by e , the motion itself by s . The deviation is proportional to the force and to the square of the time: so the force is

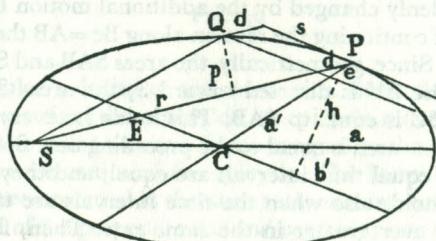


Fig. 42

found by dividing the deviation e by the square of the time interval. Because of the law of areas the time interval may be replaced by the area described by the radius vector. By taking the time interval and the motion s ever smaller

the area can be rendered ever more exactly by the triangle SPQ. Newton derives that $PE = a$, half the major axis.

Dropping a perpendicular p from Q to the radius vector and a perpendicular h from P to b' ($2a'$ and $2b'$ are conjugate diameters), we have area $SPQ = \frac{1}{2}P$; because of the similarity of the triangles PQV and PEW, we have $p : h = s : a$ or $p = h \cdot \frac{s}{a}$; hence for the area we find $\frac{1}{2}s(h : a)$.

The deviation e is related to the small distance d on the diameter by $d : e = a' : a$. For the distance e we have, by considering the ellipse as the projection of a circle, the relation $e \times 2a' : s^2 = a'^2 : b'^2$

so that

$$e = \frac{1}{2} \frac{a'}{b'^2} s^2; d = \frac{1}{2} a s^2 : b'^2$$

Then the force is

$$\frac{1}{2} \frac{a s^2}{b'^2} : \frac{1}{4} r^2 s^2 \frac{b^2}{b'^2} = \frac{2a}{b^2 r^2}$$

Here all the quantities depending on the position of the planet in its orbit have disappeared. So for all the points of the ellipse the force is as the inverse square of the distance to the sun.

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