the sphere of fire where, according to Aristotle, comets were situated. Thus the region beyond the moon was not, as Aristotle had supposed, eternal and unchanging. By giving so severe a blow to the Aristotelian theories, Tycho Brahe helped to remove one of the chief obstacles to the progress of the Copernican theories.

The first attempt at a physical explanation of the rotation of the earth was due to William Gilbert who, in his "De Magnete", published in 1600, ascribed it to the magnetic properties of the earth. Gilbert found that his terella or magnetized sphere rotated under the influence of a magnetic field. Though Gilbert's theory was not correct, by providing a plausible explanation of the rotation, it removed an objection to the Copernican system and it was accepted by Kepler and Galileo as a tentative hypothesis.

In 1609 Kepler published his book "De Motibus stellæ Martis", announcing his discovery and proof of the elliptical orbit of Mars, which was destined to cause the final disappearance of eccentric and epicyclic circles. This remarkable discovery would not have been possible if Kepler had not accepted the heliocentric theory. In the same year Galileo constructed his first telescope. In 1610 his discovery of the satellites of Jupiter was announced in the "Sidereus Nuncius"; in 1611 he discovered sunspots, which he announced in 1612 in the "Discorso" and more fully in 1613 in the "Istoria e dimostrazioni"; he also observed the phases of Venus and Mercury. These observations of Galileo made it seem probable by analogy that the earth rotated on its axis and that, with the other planets, it revolved about the sun.

When the attack on Galileo was made by the Catholic Church, the "De Revolutionibus" was placed on the papal "Index" in 1616 and declared heretical. The book was only allowed to be read provided all passages referring to the motion of the earth were altered to assert that this idea, though false, was introduced merely as a mathematical hypothesis to simplify the calculations. The Tychonic system, unlike the old Ptolemaic system, could be reconciled with these new discoveries, and it therefore remained as the only serious competitor to the Copernican system, though it was generally modified to admit of the rotation of the earth. Nevertheless, by the end of the seventeenth century, the Copernican system had finally displaced the Tychonic system. This was not because direct observation had provided any confirmation of the Copernican system, but because the heliocentric system was better adapted to the physical and mechanical explanation of the planetary motions. It fitted in naturally with Newton's mathematical demonstration of Kepler's laws of planetary motion in terms of universal gravitation. Observational proof of the revolution of the earth round the sun was eventually provided by Bradley's discovery of aberration, announced in the *Philosophical Transactions* in 1729; the first definite detections of the parallax of a fixed star came long afterwards and were announced almost simultaneously by Bessel in 1838, by Henderson in 1839 and by Struve in 1840. But the Copernican system had become firmly established and universally accepted long before these observations had proved its truth. With its acceptance, the conception of a small geocentric universe had finally to be abandoned, and a profound revolution in human thought and outlook had been accomplished.

THE WORK OF COPERNICUS

AT the meeting of the Royal Astronomical Society, held at Burlington House on May 14, Prof. Herbert Dingle gave an address on Copernicus, which supplements in some respects the article by Dr. Spencer Jones printed above. It is not generally known that Copernicus attained some proficiency in languages and even published a translation from Greek into Latin of the poems of Theophylactus Simocatta. He possessed some artistic skill, and the famous clock tower of the cathedral at Strasbourg contains a copy by other hands of his self-portrait.

In spite of his attainments, more especially in the realm of astronomy, Copernicus had a natural humility which led him to shun publicity both for himself and his work, and he was even prepared to depreciate his own worth in comparison with that of others. His dread of derision, not the fear of persecution, was largely responsible for the delay in the publication of his great work, "De Revolutionibus Orbium Coelestium". There is no evidence that he concealed his thoughts because he dreaded persecution—a popular belief which probably emanated from the fact that his work was not published until the end of his life. Many years before this, his views were well known wherever astronomy was studied because he had circulated (in manuscript form) a summary account of his astronomical system. Although this was limited to those capable of judging, his reputation was established, and ten years before his death the papal secretary delivered a lecture on his system to the Pope and his Court. No question of persecution arose as a result of promulgating his views, and he was obviously held in high esteem even in middle life, because so early as 1514 he received an invitation from the Lateran Council in Rome to assist in the reformation fo the calendar. His grounds for refusal are interesting; he held that such a reformation could not be carried out adequately owing to the incomplete knowledge of the motions of the sun and moon.

It must not be assumed that because there was no fear of persecution Copernicus was not subjected to ridicule. Luther poured contempt on his system and even predicted that he would overturn the whole science of astronomy—a prediction which was literally fulfilled, but not in the sense intended by Luther. Twelve years before his death he had been satirized on the stage at a place near Frauenberg, and this and various misunderstandings of his views were very painful to his sensitive nature. In the dedicatory letter to the Pope, prefaced to "De Revolutionibus", he admits that misunderstanding had been responsible for preventing him from publishing his views previously.

It is sometimes assumed that Copernicus' work is of a very controversial nature, but it is not primarily polemical; it is a complete treatise on astronomy in which the centre of the earth is discarded in favour of the centre of the sun as the stationary point of the universe. The arguments in favour of this new view occupy a relatively small portion of the work, and the greater part is concerned with descriptions of the movements of the celestial circles, with mathematical theorems, and with astronomical tables which were intended to supersede the earlier collection. While his tables were an improvement on the older tables, they soon became obsolete under the observational work of Tycho Brahe, and in the light of present-day knowledge the accomplishments of

Copernicus seem very small. He merely assigned the diurnal motion to the rotation of the earth, and the annual motion to its revolution round the sun, and from these postulates he worked out the astronomical consequences by means of the old devices of eccentricities and epicycles. A certain amount of simplification was introduced into the Ptolemaic scheme by reducing the necessary number of circles from about eighty to thirty-four, and in addition, credit is due to Copernicus for improving the elements of the planetary orbits. It is difficult for us now to understand why such a book—far from objectionable on religious grounds—should have been declared heretical sixty-three years after the death of Copernicus and placed on the Papal Index, from which it was not removed until 1835. The reasons for this step are interesting in view of the fact that the Church at first offered no opposition to the views of Copernicus.

When the stars were believed to move round the earth the universe could not be considered infinite; such a conception would imply that some stars were moving with infinite velocity to complete their diurnal course. When Copernicus transferred the diurnal motion to the earth there was no fundamental objection to infinite space, and this challenged the existing philosophy of Christianity. The Church held that there could not be an infinite material universe, with no abode of the blessed beyond the outermost sphere, and hence the views of Copernicus were a potential source of heresy. Even in the days of Bruno the discoveries of Copernicus were unhinging men's minds, and this little world was regarded in a new light. The new learning was easily used as a lever to displace the antiquated system which had come down from Aristotle.

It is not easy to decide definitely about the view of Copernicus himself on these matters, or to discover whether he considered his system a real account of the universe or merely a calculating device. Arguments can be adduced in favour of either opinion, but, as Prof. Dingle pointed out, at the time of the next centenary of "De Revolutionibus", it will be difficult if not impossible to understand what all the controversy was about. The question is: "Is a scientific explanation of a phenomena the real truth?" Assuming that two different mathematical descriptions of a physical situation are equally consistent with the facts, which is the true one? A definite general answer has been given in the present century, and that is that the aim of science is to save the phenomena, in other words, to find a rational connexion between the observations. When this is done, the word 'real' or 'true' is a meaningless label, and of the two descriptions assumed we may adopt whichever we wish.

In the days of Copernicus this answer had not been formulated, though its validity was admitted in very obvious cases. Whatever may have been his own view of his work, we see it now as one of the greatest landmarks in scientific history, and without it the work of Kepler and Newton, and hence of modern dynamical astronomy, would have been impossible.

Many find it difficult to understand how an original thinker like Copernicus could accept the metaphysical principles which seem so baseless to-day. In answer, it may be pointed out that consistency is not a *sine qua non* of greatness, for if it were, the first great man has yet to be born. Millions at present believe that three independent persons are yet one God, but many of these allege that physics is talking nonsense when it suggests that a wave and a particle are yet one electron. Copernicus has one outstanding distinction, even if he was unable to free himself completely from illusions. In an age when even the greatest were unable to escape from astrological speculations, he alone transcended them altogether. He undertook the complete reform of astronomy, the erasure of the product of two thousand years of toil, and a rebuilding of the whole edifice, and he takes his place among the great original thinkers of history.

CO-ENZYMATIC REACTIONS

By PROF. J. K. PARNAS
Member of the Academy of Sciences of the U.S.S.R.

THE development of biochemistry, during the last two decades, has largely increased the number of known components of organisms, and beyond discovering them and surveying their distribution, biochemistry was able to assign to many formerly known and newly discovered substances their part in the structure of living matter, their part in the chemical reactions occurring in cells and tissues, and in the regulation of the functions of the organs. The large increase of our materia biochemica was proceeding simultaneously with the elucidation of the mechanisms of biochemical reactions, which appear, now, quite different from what could be imagined twenty years ago; not only in the complexity of the intermediary transformations leading to the final products, but especially as concerns the nature and the numbers of reagents—of the organism's own reagents, of course—taking part in them.

Many chemical transformations which take place during the metabolism in cells and tissues have been resolved, indeed, into series of intermediary reactions, linked together in such a way that the products of earlier reactions are transformed in later ones: the final balance of the series gives the equation of the transformation of initial substrates into final products. Of the products of intermediary reactions, some become substrates of the reactions which follow, others appear as final products in the balance. Such intermediary reactions which cannot be resolved into series of two or more may be claimed to be primary reactions; this claim is not, however, a conclusive one, because further research may reveal as a balance of a complicated series even such reactions which at present do appear simple enough to be primary ones. The investigation of enzymatic reactions with pure isolated enzymes and co-enzymes may be considered at this moment to be the most promising tool for resolving balances of biochemical series into primary reactions.

The ideas concerning co-enzymes and co-enzymatic reactions are given here in short. They represent the views of the present author, and are entirely different from the views held by O. Warburg and by H. von Euler, and others[1].

The primary reactions are sometimes much more complicated than final balances. This is so, because not only initial substrates are transformed in them, and such intermediary substrates which are derivations of the initial, but also substances which are not related to the initial substrates, and which do not appear in the final balance, because after disappear-