the co-factor requirements of these enzymes alone. It appears that a purely chemical explanation of the biological activity of potassium in plants, or for that matter in animals, has still to be found.

Sir Rudolph Peters and the audience warmly welcomed Sir John Russell, who in a short talk described how the recent advances in our knowledge of the deficiencies in trace metals were made partly by intelligent interpretation of mistakes in farming, partly by accident, but to a large extent by the application of spectrographic analysis. He gave some instances such as the important economic effects resulting from the realization that certain soils in Australia and New Zealand were deficient in molybdenum, zinc, cobalt or copper, or in combinations of these. He also described briefly the use of iron chelates in Florida.

Dr. D. P. Cuthbertson, director of the Rowett Research Institute, Bucksburn, Aberdeenshire, had most generously agreed to deputize for Mr. Hedley Marston, the head of the Nutrition Division of the (Australian) Commonwealth Scientific and Industrial Research Organization, who was prevented by illness from attending the meeting. Dr. Cuthbertson surveyed in a masterly manner the importance of metals in the nutrition of plants and, in a more cursory manner, of animals, and emphasized the economic importance of the recent work on the importance of the metal content of soil and pasture for the nutrition of sheep and cattle. In the first place, he directed attention to the very specific requirements for metals of both plants and animals. Thus sodium, which is most important in the electrolyte metabolism of animals, does not appear essential for any plant species studied. Certain plants have a very specific capacity for storing certain metals and sometimes in an unexpected manner; thus, legumes are particularly rich in calcium, deciduous fruits in potassium, and some tropical crops have high contents of manganese. Hickory accumulates aluminium and zinc, and the Brazil nut stores barium. Metallic mercury has been observed in the seed capsules of *Holosteum umbellatum*. Iron, copper and vanadium are found in the respiratory pigments of hæmoglobin, hæmocyanin (Cephalopoda and Crustaceae) and hæmovanadin (Ascidae), respectively. Dr. Cuthbertson then mentioned some of the enzymes which contain metals as essential parts of their structures. Thus iron is present not only in hæmoglobin, but also in catalase, the various cytochromes and peroxidase. Zinc is present in carbonic anhydrase. Copper–protein complexes have been isolated from both animal and plant sources, some of which function as enzymes, such as polyphenol oxidase and ascorbic acid oxidase. In this connexion it is of interest to note that workers in the Rowett Research Institute have demonstrated the presence in herbage of a copper–peptide complex which has a greater biological effect than cupric ions in curing copper-deficiency in rats. Recently it has also been shown that molybdenum forms part of the prosthetic group of the enzymes xanthine oxidase and that of nitrate reductase.

Dr. Cuthbertson next discussed the deficiency diseases which may arise in plants or animals through lack of various metals. Lack of magnesium in plants, for example, produces characteristic changes in foliage, and deficiency of this metal is especially serious for fruit trees. Lack of potassium has also been shown to be particularly important for fruit trees. In Australia and New Zealand traces of molybdenum have improved clover production and both there and in the United States the rectification of zinc deficiency has greatly increased the citrus crop. Deficiencies of copper and cobalt have been particularly important for ruminants, and the rectification of such deficiencies in certain areas of Australia and New Zealand particularly has increased agricultural production in certain areas by amounts equivalent in value to many millions of pounds per year. There are also areas in the United Kingdom where grazing ruminants suffer from deficiency of cobalt or copper, and there are certain areas where the growth of horticultural crops—cauliflower in particular—is affected by molybdenum deficiency in the soil. There is now a considerable body of evidence showing the importance of trace-metal interaction—effect of the character of soil and of manurial treatment on the availability of metals to plants. Examples of such antagonism are provided by the interaction of iron and manganese and the observation that a high intake of molybdenum may inhibit assimilation of copper. In conclusion, Dr. Cuthbertson emphasized the interesting relationships which are being uncovered between the identification of metals as constituents of enzymes on the level of biochemistry, the nutritional importance of metals in the nutrition of plants and animals and the application of this knowledge to practical farming all over the world.

EDMOND HALLEY: THE FIRST GEOPHYSICIST

By Sir EDWARD BULLARD, F.R.S.

THE three hundredth anniversary of the birth of Edmond Halley falls this week. When he was born on October 29, 1656, the kinematics of the solar system was understood; but the rest of physical science was little more than disconnected fragments. A few principles or laws, such as the isochronism of the pendulum and Snell's law of refraction, were known, but there was little sign of the immense power and utility of the combination of experiment and systematic theory.

By the time of Halley's death in 1742, all this was changed and a body of knowledge and speculation existed that is recognizably the basis of modern science. It is scarcely an exaggeration to say that a single generation invented the technique, and discovered the content of physical science. What is more surprising, they were, in large measure, conscious of what they were doing. They believed that any fact was worth noting and any natural or industrial process worth investigating. As a young man, at

Oxford and in London, Halley knew all the leading figures interested in this new way of approaching knowledge, and soon became himself one of the best known of them. He was interested in and wrote about everything—mathematics, astronomy, ship's tackle, meteorology, magnetism, diving, archæology, the Chinese language, and how to stop ants climbing trees.

In retrospect the science of the period is overshadowed by Newton's demonstration that the motions of the solar system are a consequence of the principles of dynamics combined with the law of gravitation, and others are apt to be judged by their relation to this achievement. By this test, Halley ranks high as the friend and helper of Newton, who provided the stimulus that led to the publication of the "Principia" and as the developer of Newton's ideas on the orbits of comets. Celestial mechanics was the fashionable subject of the succeeding century and the interest in it has somewhat obscured Halley's other work.

One of Halley's earliest interests was in terrestrial magnetism. At the age of sixteen, while still at school, he made a determination of the magnetic declination at London, finding it to be $2\frac{1}{2}°$ to the westward. Twenty years later he collected all the available observations and wrote two papers in the *Philosophical Transactions of the Royal Society* which are remarkable for their insight into the real difficulties of forming a satisfactory theory of the Earth's magnetic field. He correctly followed Gilbert in supposing that the Earth's field is of internal origin, but this led to a difficulty. The change in the declination at London between the earliest measurements in 1580 and those of Halley was 14°, and similar changes were taking place all over the world. He saw that such changes could not be accounted for by movements of magnetized material within the earth without "very wonderful Effects in changing the Axis of diurnal Rotation, and . . . strange alteration in the Sea's Surface, by Inundation and Recesses thereof such as History never yet mentioned". At the same time, the great areas over which the declination had the same sign suggested that the cause was at a great distance from the surface of the Earth. These considerations led Halley to suppose that the causes of the slow variation of the declination lie deep within the Earth, and to suggest that the Earth might possess a magnetized core within a magnetized shell and that the core rotates slowly relative to the shell. He saw that such a hypothesis could account only approximately for the observations and suggested that there might be a series of concentric shells within the Earth each carrying its own set of poles.

This argument and its conclusions come very close to the theories of terrestrial magnetism that are fashionable to-day, except that we can escape the necessity for multiple shells by supposing the core to be liquid and thus to be capable of more complicated motions than the rotation of Halley's solid core.

The interest of the papers is, however, not so much that Halley was largely correct in his arguments and conclusions, as in his approach to the problem. He accepts from the start that this is a complicated subject, that a great many observations are needed and that there is no quick and simple answer. He does not try, as did Bond before him and Whiston after him, to make the observations fit some simple empirical law. He requires the motions and stability of his core to be governed by Newtonian dynamics, but expects that there will be a long period of groping for the relevant factors and that he can only "propose an Hypothesis which after-Ages may examine, amend or refute".

This realization of the complexity of the problems of geophysics is characteristic of Halley, and has only been fully regained in our own day as the tidal wave of observational data has swept away so many tidy generalizations.

Halley had a real delight in collecting observations, discussing them, and devising visual presentations of them. The successive editions of his magnetic charts, with their "Halleyan lines" of equal declination, were used for many years after his death and must have been of great practical value. His wind charts show the trade winds and monsoons with great clarity and considerable detail. In discussing the results he says that, on an Earth covered with water, the north-east and south-east trade winds would doubtless circulate continually all round the Earth, but that on the actual Earth the presence of the land disturbs the regularity of the pattern and produces local phenomena such as the westerly winds of the Guinea coast and the south-west monsoon in India. This approach, with its distinction of a general circulation and local disturbances, is sound enough ; but unfortunately the explanation proposed for the general circulation is incorrect. It is surprising that Halley, having studied the winds so carefully, did not anticipate Hadley in realizing the importance of Coriolis forces in atmospheric motions.

Halley's approach to lunar theory is along the same lines. It was known that after a period of 18 years and 11 days the positions and velocities of the Earth and the Moon return very closely to those that they had at the beginning of the period. Halley suggested that after this period, the errors of the lunar tables would repeat themselves, and that after observing for one such period empirical corrections to the tables could be derived and used in the future. He first devised this scheme as a young man, but only seriously started the observations in 1721 when he was sixty-five years of age and he completed the eighteen years of observations two years before his death. The tables were published posthumously in England and in France.

Several other examples could be given of investigations involving the discussion of a large body of data and its reduction to some kind of order ; such, for example, as the discussion of the births and deaths at Breslau and the calculation of an annuity table from them. His work on comets involved the calculation of orbits for all those for which sufficient observations existed. In addition to the well-known discovery that some comets are periodic, he noticed that their orbital planes were distributed at random, in sharp distinction to those of the planets. To collect the observations and reduce them must have been a very great task ; it is characteristic of Halley that he not only carried the work to completion, but also extracted two major discoveries from it.

Halley's great achievements in theoretical geophysics and in the discussion of observations are the more remarkable when it is remembered that he was also a naval captain, who took a 64-ft. ship southwards to the antarctic ice and also made a detailed survey of the English Channel, and that much of his time was spent in experiments on diving, in the improvement of instruments and in the translation of ancient mathematical texts from Greek, Arabic and Hebrew.