but the name completely disappeared in the second edition after Landau had discovered that Kakeya had been anticipated by Eneström. Again, Hardy associates Ramanujan's name in Lecture VIII of the present volume with the asymptotic formula for the number of partitions of n . The proof depends upon Cauchy's integral for a function of a complex variable, a subject of which Ramanujan knew practically nothing. Of course the first suggestions as to the possibility of such results and some indication of their form were due to Ramanujan, and no doubt he was full of suggestions as to the form the final results should take. There would obviously have been no such formula without Ramanujan, and one can easily understand Hardy's gratitude for having come in contact with Ramanujan.

In attempting to assess the standing of Ramanujan as a mathematician, it is difficult not to be influenced by admiration and wonder at his success in becoming a professional mathematician

in spite of the greatest difficulties. The estimate depends, as for all mathematicians, essentially upon the novelty and importance of his original work. Though some of it was wrong, and some of no permanent value; though some was overspecialization of results embodied in general theory; though some of his most interesting work was anticipated or not proved, nevertheless, there remains an impressive and formidable balance which has had great influence in shaping the direction of some of the best research since his death. To very few other mathematicians are Klein's remarks made many years ago so appropriate as to Ramanujan. "The secret of gifted productivity will always be that of finding new questions and new points of view, and without these mathematics would stagnate. In a certain sense, mathematics has been advanced most by those who are distinguished more for intuition than for rigorous methods of proof."

THE COSMICAL ABUNDANCE OF THE ELEMENTS*

By PROF. HENRY NORRIS RUSSELL

EIGHTY-EIGHT chemical elements have been isolated. Their separation by chemical means is sometimes easy, sometimes very difficult, and the best available tests differ greatly in sensitivity. Spectroscopic analysis provides a test for all constituents at once; but these tests, too, are unequally sensitive. Fortunately, the two methods supplement one another.

The composition of the earth's crust—above an arbitrary depth, such as ten miles—is well known. Oxygen is the most abundant element, whether by weight or number of atoms. Silicon is next, and then aluminium, iron, magnesium, calcium, sodium and potassium. These eight elements account for 98 per cent of the whole mass—the hydrogen in the oceans for but a quarter of the remainder.

The high mean density of the earth, and the seismological evidence for a liquid core, show that the 'crust' is not a fair sample of the whole. We may hope to do better with meteorites, taking an average of the various types (stone, iron, sulphides) in the ratio of their abundance (10 : 2 : 1, according to Goldschmidt). The result is significantly, but not greatly, different. Iron, magnesium, nickel and sulphur are more abundant; silicon, aluminium, and the alkali metals less. Just these differences are to be expected if the granitic 'crust' of the

earth has segregated from a main mass similar in composition to meteorites.

Recent photographic observations of bright meteors show that their orbits were elliptical and of short period, so that they are samples of the solar system rather than the cosmos. Other selection processes may have operated. The spectra of comets suggest strongly that some of the solid bodies whence the gases escape may be composed largely of carbon compounds. Such a body accompanying a stony meteorite in its flight through the earth's atmosphere would be immediately destroyed.

Outside the earth, we must rely on the spectroscope alone. In the stars, the conspicuous differences along the spectral sequence are known to arise from differences of temperature and ionization. Miss Payne's conclusion (1925) that the general run of stars are very similar in composition has been fully confirmed.

Sixty elements have been identified in the sun; and the apparent absence of almost all the rest explained by unfavourable situations of their ultimate lines in the inaccessible ultra-violet. More than forty have been identified in Pegasi.

On good *coudé* spectrograms, equivalent widths of stellar lines may be well measured; and the data for the sun are extensive. To find from these the 'effective numbers of atoms above the photo-

* Abstract of an address delivered at the symposium on September 26, in connexion with the celebration of the fiftieth anniversary of the University of Chicago.

sphere' concerned in producing the line demands a knowledge of the curve of growth. Its theoretical form is well known, but involves the temperature of the atmosphere, the broadening of the stronger lines by collision damping, and the possible effects of turbulence—all involving parameters which must be found from observation.

The 'effective number of atoms' depends on the degree of ionization of the element, the Boltzmann factor for the lower state involved, and the transition probability (or *f*-value). The first two may be found from the observations if the third is known for enough lines. We have to depend for these at present mainly on an approximate theory. Good observed values are badly needed, and are now being obtained. The position of the 'photosphere' depends on the general opacity and its variation with wave-length (for which our best values still come from the limb-darkening of the sun).

The most comprehensive attempt at quantitative analysis of the sun's atmosphere is still my reconnaissance in 1929, based perforce on Rowland's estimates of intensity, and omitting many refinements for lack (at that time) of data. The calibration thus derived turns out to agree surprisingly well with modern curves of growth.

An analysis by Dr. Leo Goldberg, with all present refinements, is in progress. Through his generosity a comparison with his unpublished results may be presented. They cover at present only the more abundant elements. Omitting elements for which the older determinations were noted as doubtful, the logarithms of the number of atoms above the photosphere differ, on the average, by ± 0.28 , corresponding to a factor of 1.9, while the range in abundance is 200,000-fold. Allowance has here been made for differences in the assumed temperature of the solar atmosphere, and in zero point. Goldberg's absolute values are smaller by a factor of about 30, owing to allowance for collision damping, which was unthought of in 1929.

For these same elements, the relative abundances in the sun, and in meteorites (according to Goldschmidt) show an average discordance of ± 0.45 in the logarithm, which in view of the uncertainties of determination does not indicate any definite difference in composition. For the rarer elements, the solar values of 1929 are smaller than Goldschmidt's by a factor as great as 20 for the rarest. The abundance of these elements, unlike the others, is found from very faint solar lines. An error in the old calibration of such lines (which was difficult) would account for the discrepancy.

There is therefore no present reason to conclude that meteorites differ in composition from the sun's atmosphere, so far as the metals are concerned.

For the lighter non-metals, the situation is very

different. Carbon, nitrogen, oxygen and sulphur have lines in the infra-red, from which the numbers of atoms in the corresponding excited states can be found. But the Boltzmann factors are very large, and the temperature is not known well enough to permit their accurate evaluation. The hydrogen lines are so sensitive to broadening that they cannot be used to obtain its solar abundance.

No fewer than six indirect methods have been developed by various investigators. These give for the ratio of the number of hydrogen atoms to that of all the metals together values ranging from 1,000 to 8,000.

The inert gases show no absorption lines in the sun. This serious gap in our knowledge has been filled by an investigation by Unsöld based on measures of line-widths in spectra of the star τ Scorpii, taken at the McDonald Observatory. This gives what appear to be reliable values for the abundance of the light elements, and also of magnesium, aluminium and silicon. For every atom of magnesium or silicon (which are almost equally abundant) there are approximately three of carbon, six of nitrogen, sixteen of oxygen, eighteen of neon, 3,000 of helium, and 16,000 of hydrogen. The enormous preponderance of hydrogen is again confirmed, and helium turns out to be a rather good second. Fluorine, sulphur, phosphorus and argon should be determinable in the same way.

Only the large differences in composition among the stars can be detected, pending study of high-dispersion spectra. The most notable example is furnished by the stars of classes *R* and *N*, the spectra of which show enormously strong bands due to carbon molecules and carbon compounds. Here there is no doubt that, as the late R. H. Curtiss first suggested, we have to deal with reducing atmospheres in the ordinary chemical sense, containing more carbon than oxygen, while the great majority of the cooler stars have oxidizing atmospheres, the excess of oxygen permitting the formation of the metallic oxides, which show in their spectra.

At higher temperatures, where compounds are dissociated, differences in composition are spectroscopically less conspicuous. One star of about the sun's temperature, *R. Coronæ Borealis*, has been found by Berman to contain carbon in great excess, and little hydrogen; and another, *v Sagittarii*, analysed by Greenstein, shows helium in great preponderance, and hydrogen almost absent.

In the gaseous nebulae, and the envelopes of novæ, the density is very low, and the dilution of the exciting radiation great. These conditions strongly favour the emission of forbidden lines, and favour the detection of those elements which have such lines accessible. Nitrogen, oxygen, fluorine,

neon, sulphur, chlorine and carbon have this advantage. Hydrogen and helium, which show strong permitted lines, must be very abundant. The metals are at a great disadvantage, but faint lines of several have been found. Allowing for the very different conditions of excitation, there is small evidence of composition differing from the stars.

The isolated atoms and molecules which absorb interstellar lines are all in the lowest component of their ground-states. Magnesium, silicon, and many

other elements are thus removed from observation, and the spectra of the rest reduced to a very few observable lines. Sodium, potassium, calcium, titanium and iron have been detected, and the compounds CH and CN. The electron-abundance, found by comparison of Ca and Ca^+ , shows that hydrogen, though not directly observable, is very abundant. In general, there appears to be a great similarity of composition, except for the solid bodies, which are just what might be expected in masses segregated by condensation.

BIOLOGY IN HUMAN RELATIONS*

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BRITISH SOCIAL HYGIENE COUNCIL

VICTORY of arms will not remove the causes of war. These lie in the lack of ability, character and emotional development of man himself. If the forces he has created are to be readjusted and canalized to human service and welfare, it is urgent to fit man for the task. The recognition of this possibility and a concentration of effort in an endeavour to understand and improve the quality of man, both of to-day and to-morrow, intellectually, emotionally and physically, would give a re-birth to hope.

The attempt of the Economic Conference to reduce financial tensions by a planned money policy failed owing to the recognition that man has not attained a standard of integrity and trustworthiness requisite to success. Countless instances exist of man's inadequacy being the barrier to progress.

Since the beginning of the century, research workers of the universities, the experimental farms, the consulting rooms and the hospitals have added much factual knowledge to our store, but its application to man has been checked by its seeming conflict with traditional values and by the barriers of prejudice and unreasoning fears inherent in man himself. Biology is being applied to his material advantage in agriculture, in medicine and in food production, but hardly at all to man himself. Psychology has been discovering why man behaves as he does and disclosing the extent to which unrecognized and repressed emotions result in individual and group action entirely contrary to the dictates of intelligence. Physiology is explaining something of the interdependence of mind and body and the results of glandular disharmony on character. Anthropology and sociology demonstrate the dependence of the individual on the

group and of the interaction between man and his environment. What we now need is a concerted endeavour to collate, interpret and apply these various discoveries.

Social biology rests on the factual contributions made by all sciences bearing on the development of man. Its task is to correlate and devise methods for their application, related to ethical principles, suited to the general pattern of each social structure.

A wide range of war and post-war problems awaits attention; to select but a few: migration and evacuation in relation to the family; nutrition and maternal mortality; miscegenation; family allowances; optimum marriage age; fertility, care and status of the unfit. The problems are legion. The present urgency is to democratize existing knowledge under responsible auspices.

An ignorant population is in danger—a prey to exploitation in the biological, as well as in the economic and political, fields. The harm can be irreparable when personality itself is injured. We see a terrifying example in the psychological conditioning of Nazi youth to cruelty and the harnessing of its emotional drive to the false values of national aggrandizement. In the biological field the same applies to the ease with which a distorted interpretation of eugenics has been imposed on a biologically ignorant population and used as a political weapon.

Even after two generations of education in Great Britain, the omission of social biology in school curricula has deprived science of an understanding public. Facts are discovered and published, but make little impression on individual practice, social behaviour or administration, as they relate to no emotionally accepted values.

Knowledge of nutrition, heredity and health is

* Substance of a paper read at the Conference on Science and World Order, on September 28.