that the difference is of serious importance. The cosine should be squared and the moment of inertia of the balance should be replaced by the time of its swing! A little thought will show that K must come in equally on both sides of the equation and so be eliminated. It is somewhat surprising to find T in the numerator, for this would seem to indicate that if the balance did not turn at all there would be—as measured by its tangent—an infinite deflection—*i.e.* 90°. Of course, the real meaning is that while the deflecting couple becomes less as T is greater, the sensibility becomes greater in the proportion of the square of the time, and the deflection goes on getting greater with increasing slowness of rotation until the whole thing becomes unmanageable on account of its too great delicacy, or until the decrement, by its consequent increase, more than compensates for the diminished stability. It is not clear what numerical results, if any, were obtained by Eötvös. By the formula now given, taking T as 60, K as 300 or thereabouts, and ϕ as 45°, the amplitude should only come out about one-seventh of the amount that the published formula would require.

It may be worth while to point out that the centrifugal force of the balance about its vertical axis, if the beam is 20 cm. long and turns once a minute, is about 720 times as great as the alteration of weight at the equator, so that if the beam were exactly in neutral equilibrium when stationary and pointing east and west it would have, in virtue of its rotation, a stability given to it under which the change in weight could not produce a steady deflection exceeding about 1/12°. No information is given as to how *k* was determined, nor is centrifugal stability mentioned. As in any system the logarithmic decrement becomes less as the stability is greater, it would be useless to determine *k* with any but the correct stability. The only method apparent to the present writer would be the addition of a stability bob equal in effect to the calculated centrifugal stability and a determination with the rotation stopped.

No mention is made of the most interesting feature in the scheme of the experiment. If the balance is in perfectly neutral equilibrium when not rotating, then the centrifugal stability is the only stability, and perfect synchronism is obtained whatever be the speed of rotation, whereas if there had been any initial stability or instability it could never be attained at any speed.

If the direction of rotation is such as to make the north end heavier than the south end, then with very small damping this end should be in nearly its highest, not in its lowest, position, as might at first be expected, at each turn.

This experiment, which, like those with the gyrostatic compass, and unlike Foucault's pendulum experiment, is best done in the tropics, is one of such interest and beauty that it is to be hoped, even in these difficult times, it may be set up and exhibited in some physical laboratory.

It is unfortunate that the author has not done justice to Eötvös, but he has prepared somewhat of a tangle which it has been a pleasure to unravel.

C. V. BOYS.

RESULTS OF VOLCANO STUDY IN HAWAII.

THE Hawaiian Observatory was founded in 1912 by the Massachusetts Institute of Technology, and financed in large measure by business men in Hawaii. Its publications have been systematic volcanologic and seismometric bulletins, and two larger reports, as well as numerous special articles. The scientific work has been done by Mr. T. A. Jaggar, director of the station, and Mr. H. O. Wood, associate. Preliminary announcement of results [1] at the end of the first five years of work reveals discoveries which may be of interest to science at large, and some of these discoveries are briefly reviewed here.

Nature of Hawaiian Gases and Flames.

The gas collected from a blowing-cone in the lava pit of Kilauea in 1912 by Day and Shepherd [2] contained dominantly sulphur dioxide, carbon dioxide, and nitrogen, subordinate amounts of the combustible gases, sulphur, carbon monoxide, and hydrogen, and only 4 per cent. of water vapour. The 79 per cent. of SO_2, CO_2, and H_2O could not, to the writer's thinking, be juvenile, but must in part result from union with atmospheric oxygen. Day had suggested that heat-producing reactions between such gases as free S, CO_2, and H, rising through the lava, would raise the surface temperatures so that the lava column might be at its hottest above instead of in the depths. Continuous recording and observation of flames, with experimental measurements of temperature and soundings of the lava for viscosity differences, show that this generalisation is well founded, and, in addition, that atmospheric oxygen is brought in contact with the magmatic gas so as to produce abundant flames of different colours. Air is sucked down at the convectional whirlpools and cascades. It is carried downward in the liquid lava lakes by foundering of porous crusts which cannot melt in the superfused lava glass. Air is also carried down in broken wall rock, in avalanches, and by burial of old talus. Lastly, with 33 per cent. volume shrinkage due to such gas reaction within the lava column as $2H_2+O_2=2H_2O$, even at high temperatures (1100° C. more or less), and with convectional gas pumping, a Bessemer furnace effect through the liquid lava may be created by indraught of air from the walls.

Of the three combustible gases H, CO, and S, sulphur is most in evidence as surface flames, carbon monoxide along with impurities may be represented by rare flames, while hydrogen probably flashes mostly to water-vapour in depth. There are whitish flames occasionally seen, and intensely hot bluish to violet flames play at all times from the glowing grottoes and chimneys. Some work has been done in an effort to photograph the flames with colour filters and panchromatic plates, and there is a promising field here for the study of flame spectra.

Nature of a Lava Column.

While it was known many years ago that some of the Hawaiian lava pools were shallow, few observers have imagined that the liquid lava, rising 600 ft. during a year within a pit much deeper than that would be found by sounding at the end of the period to be only 45 ft. deep, though still fully liquid at the surface. This was the case at Halemaumau, the inner lava pit of Kilauea, in January, 1917 (Fig. 1). Sounding was accomplished by plunging a steel pipe into the lava lake at several different locations, and

1 "The Outbreak of Mauna Loa, Hawaii, 1914," by T. A. Jaggar, *Amer. Journ. Sci.*, vol. xxxix., February, 1915, pp. 167–72. "Activity of Mauna Loa, December, 1914–January, 1915," by T. A. Jaggar, *Amer Journ. Sci.*, vol. xl., December, 1915, pp. 621–39. "Lava Flow from Mauna Loa, 1916," by T. A. Jaggar, *Amer. Journ. Sci.*, vol. xliii., April, 1917, pp. 255–88. "Seismic Prelude to the 1914 Eruption of Mauna Loa," by H. O. Wood, Bull. Seis. Soc. America, vol. v., No. 1, March, 1915, pp. 39–50. "Notes on the 1916 Eruption of Mauna Loa," by H. O. Wood *Journ. of Geol.*, vol. xxv., Nos. 4 and 5, 1917, pp 322–36 and 467–88. "Volcanologic Investigations at Kilauea," by T. A. Jaggar. *Amer. Journ Sci.*, vol. xliv., September, 1917, pp. 161–220. "Live *Aa* Lava at Kilauea," by T. A. Jaggar, Journ. Wash. Acad. Sci., vol vii., No. 9, May 4, 1917, pp. 241–43. "On the Terms Aphrolith and Dermolith," by T. A. Jaggar, Journ. Wash. Acad. Sci., vol. vii., No 10, May 19, 1917, pp. 277–81. "Thermal Gradient of Kilauea Lava Lake," by T. A. Jaggar, Journ. Wash. Acad. Sci., vol. vii., No. 13, July 19, 1917, pp. 397–405. "On Cyclical Variations in Eruption at Kilauea," by H. O. Wood, Second Report Hawaiian Vol. Obs. (Cambridge, Mass., 1917).

2 "Water and Volcanic Activity," by A. L. Day and E. S. Shepherd, Bull. Geol. Soc. Amer., vol. xxiv., 1913, pp. 573–606.

always the pasty bottom was found at fewer than 50 ft. of depth, with due allowance for the angle of immersion. This discovery, however, checked perfectly with the results of continued observation and survey which had repeatedly made record of shoals appearing in the lava, and of cascades from the liquid lake into marginal voids and over submerged ledges, after a period of subsidence. These hitherto unexplained facts at once became intelligible when it was realised that the lava column in reality is a semi-solid body filling the true crater from side to side, while the liquid lake is a gas-heated froth maintained through conduit holes honeycombing the upper part of the harder column. The basin of the lake is a shallow saucer, and convectional circulation keeps the liquid lava in motion. The famous islands and benches are of the bench magma, or semi-solid substance which forms the bottom of the liquid lake.

Thermal Gradient of Lava Lake.

With batteries of Seger cones encased in iron netting and strung on a wire, which in turn was placed within long steel pipes, measurement was made in 1917 of the thermal gradient (Fig. 2) of the liquid lava pool. Individual temperature measurements were also made of the fountaining grottoes at the margin of the lava and of flaming chimneys through blowing-cones above it. The highest temperatures, about 1350° C., were found in this air zone of free oxidation of gases; the fountaining lava reached a maximum of about 1180° C., the bright lines of the lake surface were at about 1000° C., while just below the surface the temperature was 100° lower. From here to the bottom of the lake 40 ft. down there was rising temperature. A thick lower stratum of the shallow lake showed uniform temperature between 1100° and 1200°. This lower stratum probably represents reheating due to oxidation of gas in contact with air carried down by foundering crusts. The fall in temperature towards the lake surface from the bottom up, which in the middle region amounts to 70° C. per metre, is due to surface radiation aided by gas expansion. The localised surface heating is due to surface oxygen and completion of reactions between rising unstable gas mixtures.

Dermolith and Aphrolith.

The writer has proposed these terms for fluidal lava and block lava respectively, called *pahoehoe* and *aa* by the Hawaiians, because, as the result of the investigations here recorded, he believes dermolithic *versus* aphrolithic process to represent respectively the lique-

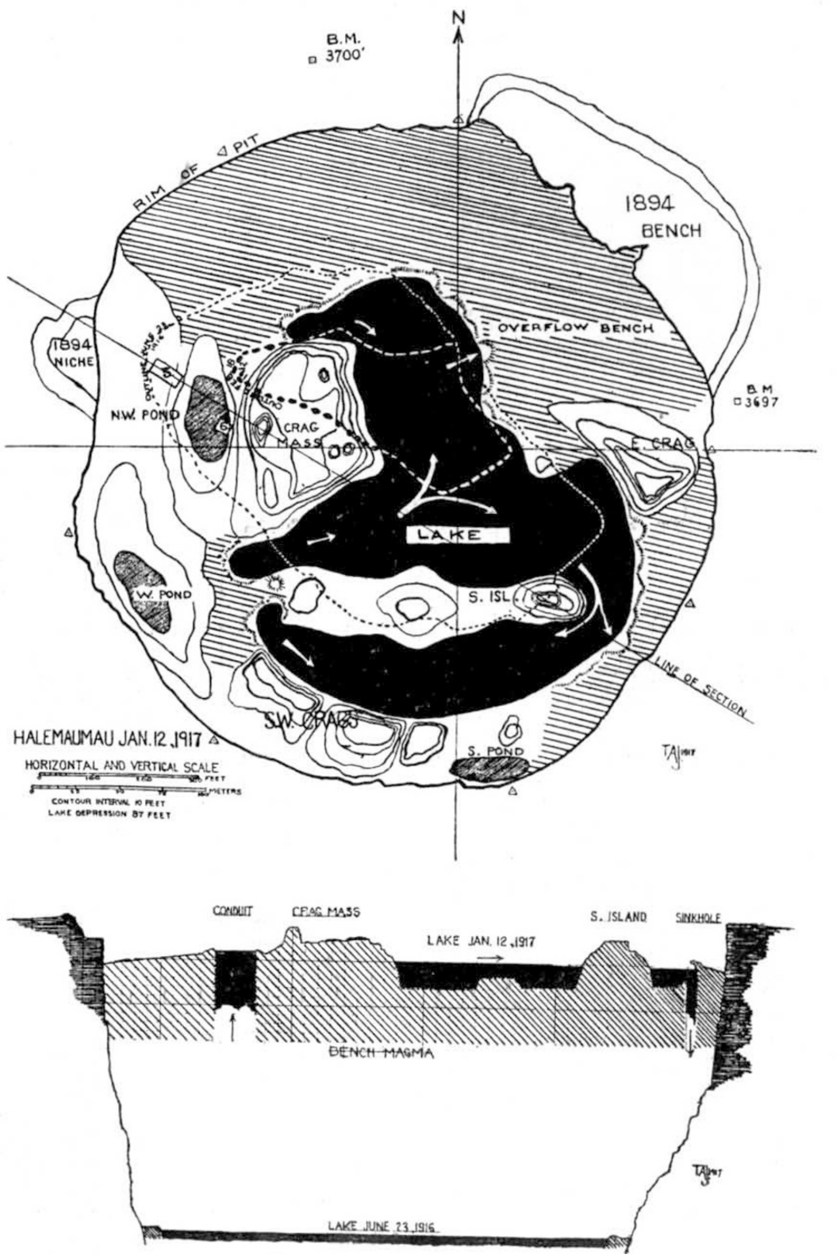

FIG. 1.—Map and diagrammatic section of Halemaumau, January 12, 1917. Lava lake in black, crusted conduit ponds shaded, overflow benches diagonal lines, raised crags contoured. Coarse dotted outline, lava lake of February 18, 1912. Fine dotted outline, June 23, 1916. Rectangle (5), site of lava spring of June 5, 1916. Rectangle (6), west corner of pool June 6, 1916. Note that N.W. corner has been conduit source on all these dates. Slight slope lake surface from conduits W. to overflow bench E. Bench magma elevated on conduit side W.S.W., subsided on sinkhole side E.N.E. Section without vertical exaggeration, lower profile shows simple rising pool of June 23, 1916. Shoal shown in lake bottom was revealed by subsidence February, 1917. Depths from soundings and subsidence records. Note progressive shoalings from W. to E. Diagrammatic sinkhole E. shows ridge of accretion on lake bottom margin which produces cascade ledge when subsidence takes place. Surveys with transit by T. A. Jaggar. Bench marks (B.M.) U.S. Geological Survey, trig stations Hawaiian Volcano Observatory. Meridian approximately 155° 17′ 8″ W., lat. 17 24′ 33″ N. This is a typical survey of the kind made frequently at Halemaumau.—From *Amer. Journ. Sci.*, September, 1917.

faction of lake magma and the gas expansion solidification of bench magma. The dermolithic basalts of Kilauea crater, characterised by wrinkled skins, have sufficiently adjusted and diminished their gas-bubble content to solidify from without inward. The aphrolithic or *aa* lava, a "foam-stone," which is expelled in a Mauna Loa flow, cools from within outward by expanding gas suddenly released from solution, and the lava disintegrates into rough units. Lava drawn

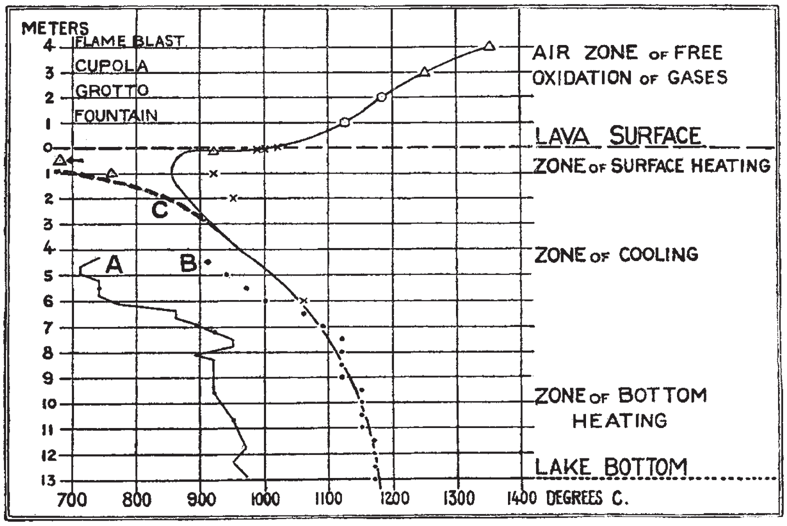

FIG. 2.—Thermal gradient of Kilauea lava lake, temperatures measured with Seger cones, 1917, by T. A. Jaggar. Triangles, circles, crosses, and dots each different series of measurements. A=actual uncorrected readings in large steel pipe. B=corrected gradient of lower lake. C=gradient to crusted lake surface when solidified.—From Journ. Wash. Acad. Sci., July 19, 1917.

up from deep within the Kilauea lake tended, on sudden cooling, to effloresce in aphrolithic fashion. An island which rapidly rose from the lake bottom proved to be typical *aa* or aphrolithic lava. The most satis-

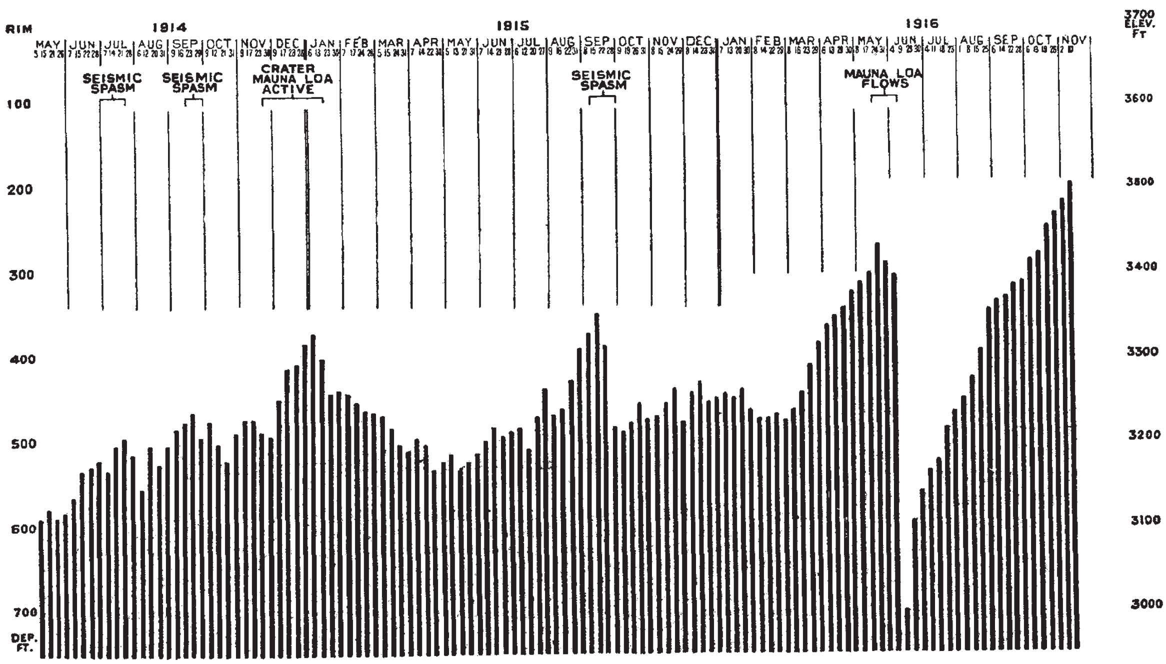

FIG. 3.—Diagram showing fluctuation of level of lava in Halemaumau, in relation to seismic and volcanic activities of Mauna Loa, 1914–16. Measurements from 120 weekly surveys by T. A. Jaggar shown.—Reprinted from *Amer. Journ. Sci.*, April, 1917.

factory feature of the discovery that the Hawaiian lava column is probably stiff within the mountain is the correlation now possible with such volcanoes as Pelée, Bogoslof, or Tarumai, which exhibited hard domes and spines instead of lava flows. The liquid or dermolithic lavas now become products of surface fusion induced by escape of gases from solution in a very stiff intratelluric magma as solvent. A volcano like Kilauea, which among volcanoes exhibits maximum temperatures, probably owes the liquidity of its surface lava to the nature of its gas reactions.

Cyclical and Sympathetic Lava Movements.

A complete eruption of Mauna Loa, the summit crater of which is twenty-two miles from the Kilauea sink and about 10,000 ft. higher, consists of a preliminary summit outburst, followed, after months or a few years, by a flank discharge with lava flow. Recently the intervals between identical phases of complete eruptions have averaged something above nine years. Kilauea has shown no hydrostatic response to Mauna Loa lava, hence it was supposed they were unconnected. It will be clear, however, that if a main lava column depends for liquefaction on surface release of gas from a stiff silicate magma solution, hydrostatics plays only a superficial *rôle,* while varying viscosity, differential expansion, and tidal stress control relative heights of lava in adjacent and connected conduits of different sizes.

During the complete eruptive period of Mauna Loa, 1914–16 (Fig. 3), five seismic spasms in that volcano, two of them accompanied by eruption, were responded to in the active lava pit of Kilauea by a series of pronounced risings of increasing duration, followed by sudden subsidences of increasing amount, as shown on the accompanying chart. The last and greatest subsidence of June 5, 1916, happened at Kilauea just at the close of the lava flow which culminated the eruptive period on Mauna Loa, and the lava column thereafter rose steadily for seven months on the Kilauea side of the system, the Mauna Loa side being sealed. There is good reason to suppose that similar sympathetic relations have existed in previous eruptions. There were no seismometric and volcanometric data on those occasions, and quantitative records are essential to establish such correspondences.

Another line of investigation, based on analysis of such lava-tide charts as Figs. 3 and 4, plotted for four and a half years, and on a study of the imperfect records from 1865 to 1911, indicates that there are larger semi-annual and smaller semi-monthly variations in the height of the lava column, after making due allowance for local interferences and longer term cycles, which vary strikingly with a time curve constructed to express the relative amounts of the forced nutational strains in the globe attributable respectively to sun and moon. Mr. H. O. Wood computed this curve, and the writer executed the lava measurements with alidade or transit for the years 1912, 1913 (Fig. 4), 1914, 1915, and 1916 (Fig. 3). It is possible that the longer term cycles vary with a strain curve of free nutation (Chandler) due to variation of latitude.

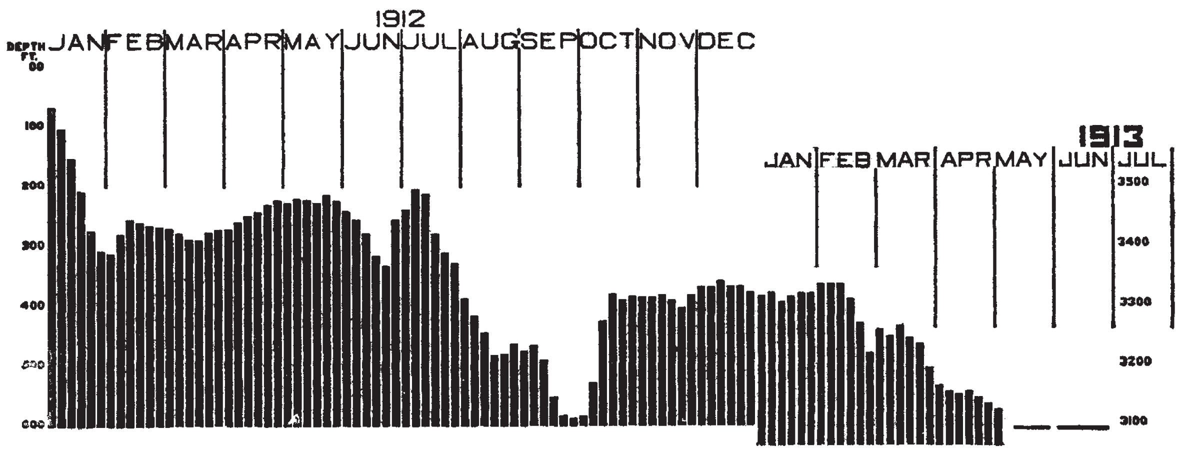

FIG. 4.—Chart showing measured rise and fall of Kilauea lava at five-day intervals during general subsidence 1911–13. Maxima near solstice, minima near equinox; supposed lunar fluctuation superposed upon this curve. Depths below rim of Halemaumau in feet (left), elevations above sea-level (right).

Seismic Indication of Volcanic Activity.

As stated above, there were earthquake swarms accompanying and preceding the outbreaks of Mauna Loa, and there have been similar groupings of local shocks accompanying the ups and downs of the Kilauea lava column. In addition, there are volcanic vibrations and extraordinary tiltings of the ground, the latter both periodic and prolonged, which promise intensely interesting data concerning the movements of the hard lava underground. Remembering the permanent surface deformation determined geodetically after the San Francisco earthquake, and after the eruptions at Usu and Sakurajima, in Japan, the writer believes, from experimental evidence, that a volcano station is most advantageously placed for critical seismometric investigation of the progress of such displacements. The co-ordination of deep magmatic movements with the earthquake problem is the profoundest enigma of geology.

T. A. JAGGAR.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

OXFORD.—The School of Geography has published its programme of lectures and other work for next term. Mr. H. O. Beckit, the acting director, will lecture on the historical geography of Europe and on problems of social and political geography; he will conduct classes on elementary surveying and on Indian geography; also, in concert with the Rev. E. C. Spicer and Miss MacMunn respectively, a field class and a special class for the study of the Oxford district. Miss MacMunn will lecture on Indo-China, and Mr. J. Cossar on "Eastern Trade Routes." Informal instruction in geography will also be given.

The Committee for Anthropology announces lectures by Prof. A. Thomson (human anatomy), Miss Czaplicka (ethnology), Mr. H. O. Beckit (distribution of man), Mr. H. Balfour (comparative technology—æsthetic arts), Prof. Sollas (stages of human culture and the latest episodes in the earth's history), Mr. Griffith (questions relating to ancient Egypt), Dr. Marett (primitive morals, religion: rudimentary forms, legal institutions of savages), Mr. T. R. Glover (progress in religion), Dr. Farnell (Greek religion), Sir P. Vinogradoff (historical jurisprudence), Prof. Macdonell (Indian religion, customs, and archæology), Mr. V. A. Smith (Indian archæology and art), and Mr. S. Langdon (questions relating to ancient Babylonia). The instruction given in many of the foregoing subjects will be of an informal character.

LORD BRYCE and Prof. R. H. Chittenden, of Yale University, were the chief guests at a dinner of American University men now in England, including the graduates of the United States Military and Naval Academies, held under the auspices of the American Universities Alumni Association, at the Criterion Restaurant on March 14. The dinner marked the inauguration of a London branch of the American University Union in Europe. Lord Bryce, in the course of an address, said he cherishes the hope that after the war there will be more and more British students in American universities to learn those subjects which are best taught there, and more and more American students in British universities. The war has given convincing proof of the unity of spirit between England and America; and in the future the two nations will