excellent papers and books of H. Poincaré, S Lie, E. Goursat, E. Cartan and Th. De Donder. For a good bibliography up to 1927, see Th. De Donder, "*Théorie des Invariants Intégraux*" (1927).

[7] Vito Volterra was the first to consider the analogues in function space of the Hamilton canonical equations. See his paper, "Equazioni integro-differenziali ed equazioni alle derivate funzionali," *R. Acc. dei Lincei Rend.*, **23** (1914).

THE COMPOSITION OF THE INTERIOR OF THE EARTH

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As is well known, the density of the earth's crust is about 2.7, while the density of the whole earth is 5.52 gms./cc. This difference is usually explained by the hypothesis that the interior of the earth is composed of heavy metals, chiefly of iron.[1] It is assumed that the heavy elements have fallen to the interior during the formative stages of the earth and stayed there.[2] This theory is, however, open to very serious objections. The iron core theory would require that about 46% of the mass of the earth consisted of iron and other heavy elements. It is difficult to believe that the composition of the earth is totally different from that of other stellar bodies. The spectroscopic examination of stars[3] and the evidence offered by the meteorites seem to show that iron forms a small part of the bulk of the stars, and while the abundance of the elements seems to be roughly the same in stars and meteorites as in the crust of the earth on the iron core theory,[4] there is complete disagreement so far as the iron and oxygen content is concerned, as the following table shows:

TABLE 1

	CRUST	STARS	METEORITES	WHOLE EARTH
Oxygen	55	50	54	35
Hydrogen	16	5	0	8
Silicon	16	6	0	9.5
Iron	1.5	2	13	46.3

Even if we assume that the spectroscopic data for iron are not complete and that the percentage weight should be multiplied by a factor of 4 or 5, iron would still form a very much smaller portion of the universe than the percentage for the earth demanded by the iron core theory.

Also, if the heavier elements are expected to sink to the interior of the planet we would expect the heavier elements of the sun to be concentrated at the center, and the surface would then consist of the lighter ones. On the planetesimal theory of the origin of the earth the tides, which were responsible for the formation of the earth from the sun consisted chiefly of the outer and lighter portion of the sun. The earth forming a very small part of the sun was probably the result of the condensation of the outer and lighter layers, and there would be very little iron in its bulk.

The hypothesis that the heavier elements of the earth sank into the interior of the planet is in itself open to objection, for this would require that all heavy elements including the radioactive ones would be more abundant in the interior than in the crust. Jeffrey has shown,[5] however, that a distribution of radioactive elements throughout the earth no greater in abundance than in the crust would prevent the earth from cooling, because of the heat liberated in the process of radioactivity.

Also, on the basis of probability the abundance of elements in the crust would be proportional, approximately, to n/d, where n is the total number of atoms of a given element present, and d is its density. On this basis one would expect iron to be at least as abundant in the crust as silicon, if the iron core theory is correct. Actually there are more than ten atoms of silicon in the crust of the earth for each atom of iron.

The foregoing considerations lead one to believe that the iron core theory is not very plausible, and other hypotheses have to be made in order to explain the high density of the earth.

The object of this paper is to present a theory explaining the high density of the interior of the earth on the basis of the ionization of the elements composing the core. The composition of the earth is assumed to be no different from that shown by other celestial bodies.

Any theory concerning the composition of the earth must satisfy the following conditions. In the first place, the theory must account for the total mass of the earth, in agreement with that observed from experiments on the gravitational constant. In the second place, the distribution of mass must be such as to give the moment of inertia in agreement with the value deduced from the known precessional constants of the earth. In addition, the manner in which seismic disturbances are propagated lead one to believe that the earth consists of two distinct layers, the upper, behaving like a rigid body, while the lower must consist of material in liquid form, inasmuch as seismic disturbances seem to be absorbed by that part of the earth. We may, therefore, assume that there is a core of radius r and of density ρ, and an envelope of thickness R–r, where R is the radius of the earth, and of density ρ_2. The first two conditions mentioned above give rise to two equations, one for the mass of the earth and the other for its moment of inertia.

$$r^3\rho_1 + (R^3 - r^3)\rho_2 = 5.52R^3 \quad (1)$$

$$r_1^5\rho_1 + (R^5 - r_1^5)\rho_2 = 4.43R^5 \quad (2)$$

We have two equations with three unknowns. The third relation between the variables may be obtained from the following considerations. As is well known the temperature near the surface of the earth rises approximately one degree C. for each 100 feet increase in depth. If this gradient prevails for large distances below the surface of the earth the temperature would soon reach a level at which decomposition or dissociation of molecules takes place, and the more volatile of the elements composing the molecules would be driven off and form an envelope around elements which are solid at ordinary temperatures. The envelope would, on this view, consist of the present crust together with most of the permanent gases contained in the earth, all other elements forming the core. If we assume that the composition of the earth as a whole is no different from that of the crust or of the upper layers of the sun, the gases, together with the crust, would form about 70% of the material of the earth and the core would make up about 30% of the mass of the earth, and we have the third relation:

$$r_1^3\rho_1 = 1.66\ R^3.$$

The simultaneous solution of the three equations gives the following values for the unknowns: $\rho_1 = 15$, $\rho_2 = 4.2$, $r = 0.5\ R$.

If the temperature gradient remains constant for the total distance $R-r$, the temperature of the core would be approximately 100,000°C.

The most probable energy of thermal agitation of the atoms corresponding to the temperature of 100,000 would be equal to the energy an electron would have when accelerated by a potential of 15.0 volts, a potential much greater than the first ionization potential for all the elements forming the core. In fact, this potential is sufficient to remove the outer shell of electrons from all mono-, di- and trivalent atoms. Corresponding ionization will be produced by collision between atoms due to thermal agitation.

Although the probability of ionization by collision is very small, and the life of an excited atom very short the velocity of atoms at these high temperatures would be so great, and the mean free path at the high pressures existing in the interior of the earth so small that the number of collisions in 10^{-8} seconds, i.e., during the life of an ionized atom would be about 10^5, a number amply sufficient to produce ionization. The calculations are based on the assumption that the considerations of the Kinetic Theory of Gases may be applied to these temperatures and pressures.

When ionization results in the removal of the outer electron shell the radius of the ionized atom may be calculated from the Bohr Theory, assuming that the radii of successive shells are in the ratio of $1^2:2^2:3^2:$, etc. While this procedure often leads to wrong results,[6] it is by far the most reliable guide available. On this basis the average density of the ionized atoms is about ten times as great as that of the unionized ones. Where the collisions at the assumed temperatures is not sufficient to remove the whole shell from some atoms of greater valence, they are sufficient to doubly and triply ionize the material.

No guiding principle exists which would enable one to calculate the radius of ionized atoms. Some work has been done on the size of ionized atoms in crystals,[7,8] which seems to indicate that the resulting radius of the atom is very much smaller than in the neutral state, but the considerations on which these calculations are based cannot be applied here. It is, however, reasonable to assume a great diminution in the space occupied, inasmuch as these collisions will result in the removal of the outer layer of electrons according to the Bohr Coster model of electronic arrangement. Under these conditions the density would easily reach a value of 15 gms./cc.

It is not necessary to have as high a temperature as 100,000°C. in order to produce these effects. It can easily be shown that a temperature of about 40,000° would be sufficient to produce the necessary ionization, if we take into consideration the Maxwellian distribution of velocities. The number of atoms which would have the energy of thermal agitation corresponding to 15–20 volts would be great enough and the number of collisions of other atoms with these frequent enough to produce the proper degree of ionization in the material of the core, especially if we take into consideration the relative velocities of the two atoms colliding.

Radioactive disintegrations may easily account for the high temperature of the interior. Lead and other products of radioactive disintegration form about 0.1% of the crust of the earth. If a similar abundance is assumed for the whole of the earth, and further it is assumed that only as little as one-tenth of this disintegration had taken place on this planet while the rest was taking place while the earth was a part of the sun the heat produced in the process of disintegration was sufficient to raise the temperature of the core to 100,000 degrees even if a specific heat of 3 is assumed for the liquid mass of the core, since the heat of disintegration is known to be about 10^9 calories/gm.

The theory outlined above accounts satisfactorily for the known mass and for the distribution of the mass inside the earth. The liquid core consequence of the theory is also in agreement with the known reflection of seismic waves from the interior of the earth. None of the assumptions on which this theory is based runs contrary to accepted facts. It must be mentioned on the other hand that too little is known concerning the properties of matter at very high temperatures and pressures, and the conclusions must, therefore, remain somewhat uncertain. However, the paper here presented has for its aim not a dogmatic explanation of the density of the earth, but rather is it an effort to call attention to a new, probably more satisfactory method of attack of the problem.

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ROTATIONAL RAMAN SPECTRUM OF CO_2

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The Raman effect provides a convenient means of studying the rotation spectrum of many molecules, and avoids many of the difficulties inherent in work in the infra-red. The principal obstacle to rapid work is the low intensity of the scattered light. This may necessitate an inconveniently long exposure time, if a high dispersion spectrograph is used. However, by extending the methods first used by Rasetti,[1] we have been able to get good photographs of the oxygen rotation band in two hours.

The gas is contained in a quartz tube about 20 in. long and 1 in. inside diameter. The walls are $^1/_{16}$ in. thick and have withstood a pressure of 400 lbs. per sq. in. Although the increased pressure improves the intensity, it also broadens the lines to such an extent that the CO_2 rotation band cannot be resolved at pressures much above 75 lbs. per sq. in.

The exciting source is a water-cooled mercury arc in the form of a very narrow U. Its effective length is about 35 in. and it operates with 10 amp. The arc and the tube are enclosed in a chromium-plated cylindrical reflector which serves to conserve the light as well as to support the apparatus. A small dish of mercury is placed inside the Hilger E_1 spectrograph. This reduces the intensity of the scattered λ2536 exciting line to such an extent that it is nearly the same as its ordinarily weak companion, λ2534. Since the structure of the CO_2 band is almost at the limit of resolution of the spectrograph, it is necessary to control the temperature very carefully during the 10 or 12 hours of the exposure. For this purpose the spectrograph is enclosed in a box made of celotex, and the temperature of the room outside is maintained constant within half a degree by a thermostat.