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THE ATMOSPHERES OF THE MOON, PLANETS AND SUN.

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IT was only a week or two before reading Professor Liveing's interesting communication in *Science* that I had made some calculations which led me to adopt the same theory which he has advocated. The object of my investigations was, in fact, to show that we could not regard the atmospheres of the different members of the solar system as isolated masses of gas, from which molecules might fly off if their speeds were to become sufficiently great, but that, to account for the very existence of planetary atmospheres at all, it would be necessary to adopt the hypothesis of an atmosphere of excessive tenuity pervading both interplanetary and interstellar space.

It is unfortunate that Mr. Howard did not apply the principle of conservation of energy to the arguments contained in his letter in the issue of April 28. Had he done so he would have realized that the question as to whether a molecule will permanently leave the atmosphere of the Moon or a planet depends only on its speed, irrespective of direction, and does not in any way depend on whether the motion takes place in a vertical direction. In fact, if the kinetic energy of a molecule is greater than the work required to be done against the planet's attraction in order to remove the molecule to an infinite distance, the molecule will describe a hyperbola, and will fly off never to return again, no matter what be its direction of motion, provided that it does not come into collision with any other molecule or with the planet itself.

Again, the speed required to leave the Earth is about five times as great as that required to leave the Moon; but this is not because the earth's attraction is five times as great as the Moon's, but because the Earth's *potential* is about twenty-five times as great as the Moon's, consequently, in order to leave the Earth, a particle would require to have twenty-five times the kinetic energy, or five times the speed, which it would require to leave the Moon.

According to the well-known "error law" of distribution of speed among the molecules of a gas, which forms the basis of calculations connected with the kinetic theory, there must always be *some* molecules moving with sufficiently great speeds to overcome the attraction of any body, however powerful, and *some* whose speed is too small to enable them to escape from the attraction of any body, however feeb e. On this assumption no planet can have an absolutely permanent atmosphere, and no planet or satellite which has ever had an atmosphere could get rid of that atmosphere entirely. If, however, the proportion of molecules which escape is relatively exceedingly small, any changes which occur in the nature of the atmosphere of the planet will take place so slowly that countless ages will have to elapse before they make themselves felt. In order, therefore, to test the relative degree of permanence of the atmospheres of different celestial bodies, I have calculated what proportion of the molecules of oxygen and hydrogen at different temperatures have a sufficiently great speed to fly off from the surfaces of, and never return to, the Moon, Mars and the Earth. I have also given the corresponding results for the Sun, not, however, at its surface, but at the Earth's distance from the Sun's centre, where the critical speed is, of course, square root of two times the speed of the Earth's orbital motion.

The numbers, which are given in Table 1 below, represent in each case the average number of molecules, among which there is *one* molecule whose speed exceeds the critical amount. Thus, for oxygen at temperature 0°C, rather over one molecule in every *three billion* is moving fast enough to fly off permanently from the Moon, and only one in every 2.3×10^{320} is moving fast enough to escape from the Earth's atmosphere, while the Sun's attraction, even at the distance of the Earth, prevents more than one in every 2×10^{4040} from escaping.

When we arrive at such vast numbers as this, it might be reasonable to object that we have pushed the kinetic theory a great deal further than it will go. The assumptions made in many proofs of the "error" law of distribution certainly preclude its application to high speeds that are so rarely attained. Still there is no physical limit to the speed which any individual molecule might acquire in the course of colliding with other molecules. As Professor Liveing has pointed out, all that would be necessary would be a sufficiently long run of collisions, in each of which the line of impact happened to be nearly perpendicular to the direction in which the molecule in question was previously moving, so that each impinging molecule should transfer the greater portion of its energy to that one molecule.

And theory points to the conclusion that whenever there is any law of permanent distribution of the molecules of a gas, that law must be the "error" law. Hence the calculations may be reasonably expected to give a correct estimate of the proportion of molecules whose speed exceeds the critical speed, provided that the mass of gas under consideration is so large that the *total* number of such molecules is great, however small their relative proportion may be. Thus we are at least justified in regarding the figures as affording indications of the relative permanency or otherwise of the gaseous envelopes surrounding different bodies of the solar system.

One great difficulty presented by the theory is that oe taking account of the differences of temperature of the atmospheres of the different bodies. There seems to be good reason for believing that the Moon's temperaturf may fall below —200°C., in which case only one molecule in 7×10^{51} will be able to escape. And generally the larger members of the solar system are the hotter, and this would cause them to part with their atmospheres more readily in proportion than they would if all the bodies were at one common temperature. If the absolute temperatures of different bodies were proportional to their gravitation potentials, the proportion of molecules possessing the speed requisite to carry them off would be the same for all. This condition would require the Earth's atmosphere to have an absolute temperature roughly twenty-five times as high as that of the Moon's. Even supposing this were the case, it does not necessarily follow that the Moon's atmosphere would be of as permanent a nature as the Earth's, for the gain and loss of molecules would only take place near the upper limits of the atmospheres, where collisions rarely occur; hence the question of permanency would largely depend upon the extent of the atmospheres surrounding the two bodies.

The figures tend to show that the Earth would lose its atmosphere very slowly, even if plunged in vacuo, and that the Sun's atmosphere may be regarded as *practically* permanent, even independently of the hypothesis of an interstellar atmosphere. But the impossibility of assuming losses to be taking place from the atmospheres of planets without a compensating accession of molecules from the surrounding space is at once evident when we endeavor to trace the past history of the solar system.

If the Moon ever had an atmosphere which has now flown off into space, losses of a similar nature must necessarily have taken place in the atmospheres of all the planets at a time when they were much hotter than they are at present, especially in the case of so small a planet as Mars. And if we trace the history of the solar system further and further back, we find that, if the planets were hotter and hotter, they must therefore have been parting with their gaseous envelopes at a greater and greater rate,—a condition of things which would render it impossible to account for the initial existence of planetary atmospheres.

The nebular hypothesis supposes the Sun and planets to have been evolved by the gradual contraction and condensation of a nebulous mass of gas. This process would be exactly the reverse of the flying-off process suggested by a perusal of Dr. Robert Ball's paper.

It is only necessary to assume the existence of a distribution of matter of excessive tenuity pervading interplanetary space, in order to account for the permanence of the planetary atmospheres at all temperatures; and such an assumption, taken in conjunction with the kinetic theory, is *quite compatible* with the absence of any *perceptible* atmosphere surrounding the Moon.

The kinetic theory enables us to compare the densities at different points of a mass of gas in equilibrium under fixed central forces, such as the attractions of the celestial bodies. If we apply the theory to the system consisting of the Sun, Moon and Earth, we shall find the relative densities given in Table 2, the density of the corresponding gas in the atmosphere at the Earth's surface being taken as unity. If we take the density at an infinite distance from the Sun to be unity, the corresponding results will be given by Table 3.

The assumption on which these results are calculated may be called an "equilibrium theory," since it takes no account of the motions of the bodies in question, and it assumes a permanent distribution to have been attained, so that the whole of the mass is at a uniform temperature.

When every allowance is made for the artificial character of the assumptions, it is still highly unreasonable to suppose that the Moon could have an atmosphere so far in excess of that required by the equilibrium theory that its presence could be detected even by the most careful observations.

And so far from its being necessary to assume the density of the interplanetary atmosphere to be a millionth of a millionth of the density at the Earth's surface, we should, on the assumption of a uniform temperature of 0°C, have to divide the latter density by a million over and over again fifty-five times, before we had reached the degree of tenuity required by the equilibrium theory for the interplanetary atmosphere in the neighborhood of the Earth's orbit. Taking the number of molecules in one cubic centimetre of air as a million million million and employing the figures calculated for oxygen, we should have to construct a cube, each of whose sides was 10^{100} kilometres long, in order to enclose a hundred molecules of a gas of this degree of tenuity. Thus, if we multiply a million by a million and repeat the process sixteen times and then multiply by ten thousand, and take this number of kilometres as the side of a cube and place one hundred molecules of gas inside it and the Earth in the middle, that hundred molecules would be sufficient to make up for any loss that is going on at the surface of the Earth's atmosphere. It is similarly evident from the figures in Table 1 that countless ages must elapse before a single molecule leaves the Earth's atmosphere, and that no perceptible equalization is taking place between the atmospheres of different planets.

If we try to compare the atmospheres of different planets, such as the Earth and Mars, the "equilibrium theory" breaks down completely. But it would be highly unreasonable to suppose that anything like a *permanent* law of distribution existed between two bodies at such vast distances apart, separated by a medium of such extreme tenuity, and subject to solar radiation and so many other disturbing causes. The molecules of gas flying about in interplanetary space are so few and far between that collisions can only rarely take place between them, whereas any tendency of approach towards a permanent state of distribution must necessarily depend on frequency of collisions between the molecules. Hence the rate of equalization of energy among the molecules of so diffuse a medium must be infinitesimally slow, so slow indeed that practically no such equalization is taking place at all. It is different in the case of two bodies so near one another as the Earth and Moon. Among the molecules of gas which at any time might find themselves in the neighborhood of the Moon and Earth, the greater number would be drawn in by the more attractive body, and the moon would not, therefore, be likely to obtain more than her fair share of air, which, as we have seen, is very small in comparison with that allotted by the equilibrium theory to the Earth.

Table 3 affords some idea of how the density of the Earth's atmosphere would increase with the gradual cooling of the solar system. According to this theory, a similar increase has been taking place in what little atmosphere there is surrounding the Moon, and at no period of its history has it possessed an atmosphere of oxygen and nitrogen comparable in density with that of the Earth. A decrease of density in a planet's atmosphere could only take place by the condensation in liquid form of vapors present in it, not by matter leaving the planet.

The figures given in Table 3 are more than sufficient to account for the comparative rarity of hydrogen in the Earth's atmosphere, but a similar argument would also, of course, require a considerable preponderance of oxygen over nitrogen, which is contrary to experience. But here again we have pushed the equilibrium theory too far. It is highly probable that the number of molecules flying about both in interplanetary and interstellar space is far greater than that given by the accompanying tables, and the inference is that the atmospheres of the planets are increasing in density at a rate far greater than that due to cooling alone. Even so, however, the few molecules picked up by the Earth in the course of a year or even a million years may have no *appreciable* effect on the density or composition of the atmosphere. Hence, while, as Professor Liveing asserts, the same chemical elements may be expected to enter into the constitution of all the celestial bodies, there appears to be no warranty for supposing them to be in any way regularly distributed as regards their relative proportions; and on the other hand

there is every reason for believing that the existing law of distribution may differ vastly from the law of permanent distribution required by the kinetic theory of gases.

TABLE 1.

Average number of molecules of gas to every one whose speed is sufficiently great to overcome the attraction of the corresponding body:

	Hydrogen at 0°C (=273° absolute) Oxygen at 4095°C (=4368° absolute.)	Hydrogen at —205°C (=68° absolute.) Oxygen at 819°C (=1092° absolute.)	Hydrogen at —246° (=17° absolute.) Oxygen at 0°C (=273° absolute.)	Hydrogen at —269°C (=4¼° absolute.) Oxygen at —205°C (=68° absolute.)
Moon's surface	3.6	610.0	2.7×10^{12}	6.9×10^{51}
Surface of Mars	3920.	5.0×10^{15}	1.0×10^{65}	1.8×10^{263}
Earth's surface	6.0×10^{19}	3.3×10^{81}	2.3×10^{329}	4.5×10^{1322}
Earth's atmosphere at a height of 80 miles.	2.3×10^{19}	7.6×10^{79}	5.7×10^{322}	1.5×10^{1296}
Sun at same distance as Earth	2.7×10^{307}	6.6×10^{1233}	2.0×10^{4940}	1.7×10^{19767}

TABLE 2.

Relative densities of oxygen and hydrogen in a permanent distribution taking their densities at the Earth's surface as unity:

	H at 0°C (273° abs) O at 4095°C (4368 abs)	H at —205°C (68° abs.) O at 819°C (1092 abs.)	H at —246°C (17° abs.) O at 0°C (273° abs.)	H at —269° C(4¼° abs.) O at —205°C (68° abs.)
Earth's surface	1	1	1	1
Earth's atmosphere at a height of 80 miles	.3859	.02268	2.414×10^{-7}	3.4×10^{-27}
Moon's surface	3.1×10^{-20}	9.4×10^{-79}	37.7×10^{-318}	3.5×10^{-1249}
At Moon's distance from Earth	4.6×10^{-21}	4.6×10^{-82}	4.5×10^{-326}	4.0×10^{-1302}
At Earth's distance from Sun	2.1×10^{-21}	1.9×10^{-83}	1.4×10^{-331}	3.6×10^{-1324}
Interstellar space	2.7×10^{-330}	4.9×10^{-1318}	5.6×10^{-5724}	9.9×10^{-21694}

TABLE 3.

Relative densities in a permanent distribution, taking the average densit of distribution of the gas in interstellar space as unity:

	H at 273° absolute O at 4368° abs.	H at 68° abs. O at 1092 abs.	H at 17° abs. O at 273 abs.	H at 4¼ abs. O at 68° abs.
At Infinity	1.0	1.0	1.0	1.0
At Earth's distance from Sun	7.9×10^{308}	3.9×10^{1235}	2.4×10^{4942}	3.6×10^{19769}
At Moon's distance from Earth	1.7×10^{309}	9.4×10^{1236}	8.0×10^{4947}	4.0×10^{19791}
At Moon's surface	1.2×10^{310}	1.9×10^{1246}	1.4×10^{4961}	4.2×10^{19844}
At Earth's surface	3.7×10^{329}	2.0×10^{1317}	1.8×10^{5273}	1.0×10^{21073}

ON THE LIFE ZONES OF THE ORGAN MOUNTAINS AND ADJACENT REGION IN SOUTHERN NEW MEXICO, WITH NOTES ON THE FAUNA OF THE RANGE.[1]

BY C. H. TYLER TOWNSEND.

THE range known as the Organ Mountains, in southern New Mexico, was determined by the U. S. Geodetic Survey, if I mistake not, to rise to a height of 8,800 feet above sea-level. This altitude has been carefully veried by observations taken by Professor C. T. Hagerty, of the Civil Engineering Department of the New Mexico Agricultural College. The western base of the range is about twelve miles to the eastward of Las Cruces, in Doña Ana County. The range runs nearly north and south for a distance of about twenty miles. It varies in width from about four to eight miles, the north extremity as well as the south one being much narrower. It is intersected a little south of the middle by a wide and detoured pass known as Soledad Cañon. The San Augustine pass divides the range near its north end. About two miles to the north of this pass begin, by common consent, the San Andres Mountains, a lower range which extends on to the northward for about fifty miles. About three miles south of San Augustine pass is a rather high and more difficult drop in the range, known as Bayler pass. The highest peaks of the Organs are north of the centre of the range, and their upper portions are mostly bare and nearly inaccessible. There is a ridge between the southernmost two peaks and those peaks to the north of them. This ridge is probably 8,000 feet or more in elevation, and its highest portion is the point to which the zones given below have been traced. It dips about 200 feet at its northern end.

[1]Read before the New Mexico Society for the Advancement of Science, at Las Cruces, April 6, 1893.

The altitude at the western base of the range is about 4,800 feet, or 1,000 feet higher than the site of Las Cruces, situated twelve to fifteen miles west on the edge of the Rio Grande Valley. Thus the above mentioned ridge is, roughly speaking, about 4,000 feet above the surrounding country, or about 3,000 feet above the base of the range.

The various points above mentioned will be better understood by consulting the accompanying diagram of the range. It is only a diagram, no attempt having been made to secure accuracy of detail.

It may be stated that, to the northeast of the range, stretch away the plains of San Augustine; while to the northwest is the vast waterless expanse known as the Jornada del Muerto, or Journey of the Dead, where seventy miles has to be covered between springs. To the eastward of the range is a vast level sandy plain which extends some eighty miles to the Sacramento Mountains, and plains stretch away likewise to the southeast, and for a less distance to the south. For some of the beauties of the Organ Mountains, I would refer the reader to a paper by Mr. Charles H. Ames, in *Appalachia* for 1892. The point reached by Mr. Ames was the lowest part of the ridge above referred to between the peaks, being the dip at its northern end.

Beginning at the east bank of the Rio Grande River, in the bottom of the valley, and going eastward until the highest portion of this ridge between the peaks is reached, the following zones, in the order given below, are encountered. The actual ascent to this ridge, during which most of the data of the higher zones were carefully noted, was made on Nov. 12, 1892. We left the house at Riley's ranch at 9.00 A. M., and reached the highest part of the ridge at about 12.15 P. M., thus making fully 3,000 feet in three and one-quarter hours. Starting back at 12.30 P. M., we reached the house again at 2.55 P. M. It should be stated that there was much snow in the dense brush through which we passed in the higher portions of the range, and that on many occasions we had to proceed in a reclining attitude over long stretches of smooth rock at an angle of about 35°. The house at Riley's ranch is 4,900 feet altitude, and the ridge, as above mentioned, about 8,000 feet.

Tornillo or Cottonwood Zone.

About 3,500 to 3,800 feet.

Characteristic plants.—Prosopis pubescens (tornillo), Populus fremontii var. wislizeni (valley cottonwood), Salix spp. including S. longifolia (willows), Aster spinosus (spring aster), Helianthus annuus (common sunflower), Helianthus ciliaris (dwarf sunflower), Xanthium sp. (cocklebur), Rhus sp. (sumach), Sphæralcea angustifolia, Solidago sp. (golden rod), Baccharis angustifolia (at its climax), mistletoe, grasses, etc.