GRAVITATION

By CHARLES F. BRUSH

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AT THE Minneapolis meeting of the American Association for the Advancement of Science in December, 1910, I had the honor to outline "A Kinetic Theory of Gravitation."[1] This was followed by a "Discussion" of the theory in 1914.[2] A second "Discussion" came in 1921.[3] A third "Discussion" appeared in 1926.[4]

The latter paper contains a concise synopsis of the theory and very convincing argument supporting my contention of 1910, that the energy acquired by falling bodies is derived from the ether.

This Kinetic Theory of Gravitation postulates that the ether is endowed with vast intrinsic energy in the form of waves propagated continually in every conceivable direction, so that the wave energy is isotropic. (The belief is expressed that *all* energy is primarily energy of the ether.)

The very high-frequency ether waves, which embody most of the ether's intrinsic energy, pass freely through matter without obstruction except that concerned in gravitation, and a very small heating effect (which will be explained later). The ether waves exert motive action on atoms or particles of matter whereby the latter are buffeted about in all directions with some absorption of etherial energy. Thus a lump of matter casts a spherical energy shadow into space, the depth of shadow diminishing with the square of distance from its origin. The energy shadows of two or more bodies inter-

[1] *Science*, March 10, 1911; *Nature*, March 23, 1911.
[2] *Proc. Am. Phil. Soc.*, Vol. LIII, No. 213, January–May 1914.
[3] *Proc. Am. Phil. Soc.*, Vol. LX, No. 2, 1921.
[4] *Proc. Am. Phil. Soc.*, Vol. LXV, No. 3, 1926.

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blend, so that energy density between them is less than elsewhere, and they are *pushed* toward each other by the superior wave energy from directions beyond them. The 1926 paper [4] explains this at length.

To aid in forming a mental picture of the relation of the very high-frequency ether waves postulated as the cause of gravitation, to other well-known classes of ether waves, I have prepared the chart of ether-wave frequencies shown in Fig. 1.

Each horizontal line in the scale of frequencies represents double the frequency of the line below it, or half the frequency of the line above it. Thus the scale of frequency increases upward by octaves as in music.

Starting at the bottom of the scale with a frequency of one ether wave per second, the first line above represents two waves per second, the second line four waves per second, the third line eight waves per second, and so on to the tenth doubling where we get a frequency of 1,024 waves per second as shown. Continuing the doubling process another ten times we get a frequency of 1,024 times 1,024, or 1,024 to the second power, and so on upward in the scale to the third, fourth and fifth, etc., powers of 1,024. Thus it is seen that the indicated wave frequency increases with great rapidity as we ascend the scale. At the twentieth octave it is more than a million per second; at the fortieth octave more than a million million waves per second.

I am indebted to a chart shown at the British Exposition in 1925; to a chart by G. L. Clark in 1927, and to a chart by W. E. Deming in 1929 for much of the material shown in my chart. But I have arranged it somewhat differently, emphasizing ether-wave frequency rather than wave-length.

Frequency is converted into wave-length by dividing the velocity of light per second by frequency of the waves per second. Thus the frequency 1 at the bottom of the chart means one wave per second, and its wave-length is the distance it would travel in one second, before another wave started after it. This is the velocity of light, about 186,000

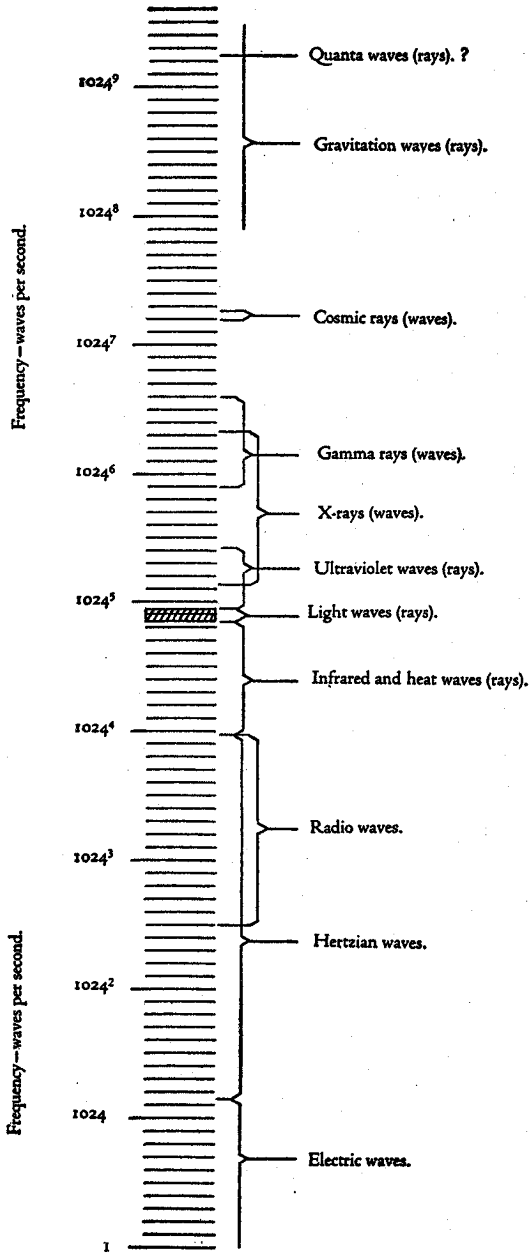

Frequency—waves per second.
Quanta waves (rays). ?
1024^9
Gravitation waves (rays).
1024^8
Cosmic rays (waves).
1024^7
Gamma rays (waves).
1024^6
X-rays (waves).
Ultraviolet waves (rays).
1024^5
Light waves (rays).
Infrared and heat waves (rays).
1024^4
Radio waves.
1024^3
Hertzian waves.
Frequency—waves per second.
1024^2
1024
Electric waves.
1

FIG. 1

miles, or about 300,000 kilometers. (All ether waves travel with the same velocity.)

A wave-train of this very low frequency and very great wave-length could easily be launched into the ether by revolving a closed coil of wire on its own diameter as an axis, in a magnetic field, at the rate of one revolution per second. If we should increase its revolutions to ten per second, we would get a frequency of ten, and a wave-length of 18,600 miles. Such mechanically generated electric ether waves may be increased in frequency without much difficulty as far up as shown in the chart.

Next above we have Hertzian waves, covering about 28 octaves, generated by the condenser and spark-gap method. The upper half of this long range of ether waves contains the waves used in radio transmission of speech and music.

Next above the Hertzian waves, of higher and higher frequency and shorter and shorter wave-length, we find the infrared and heat waves covering about 9 octaves. These waves embody most of the heat received from the sun, and nearly all the heat radiated from hot bodies below redness.

Then we come to the exceedingly interesting and intensively studied light waves or rays. These cover barely one octave of the scale, and their mean frequency is about five hundred million million waves per second. It seems unfortunate that the human eye is sensitive to such a short range of ether wave vibrations only, while the human ear can perceive about eleven octaves of sound, or air vibrations. Perhaps some animals or insects have a wider range of vision than humans.

Above the light waves we find about five octaves of ultra-violet waves. The sun's radiation includes the last three classes of waves, though some of the ultra-violet is absorbed by our atmosphere and does not reach the earth. The ultra-violet rays or waves promote chemical action and are chiefly responsible for the ordinary photographic image.

Next in the growing range of frequency we have the well-known X-rays, so extensively used in X-ray photography for therapeutic and industrial purposes. These cover a long range of octaves in our chart, and overlap the upper part of the ultra-violet range and the lower part of the gamma range. X-rays, particularly those of the highest frequencies, pass rather freely through large thicknesses of light substances such as wood, fabric, animal tissue and metals of low atomic weight and density; but metals of large density and high atomic weight absorb and obstruct them greatly. Thus a quarter inch of lead almost completely stops X-rays of the highest frequency. The ability of X-rays to pass deeply into or through matter, is called "penetrating power."

Above the X-rays in our chart are the gamma rays of radium, so extensively used in therapy. These have a much greater penetrating power than the highest-frequency X-rays.

All the above described classes of ether waves have been demonstrated experimentally, and doubtless all exist to some extent, permanently in the ether of space. Particularly is this true of the heat waves, as I pointed out in my 1927 paper.[1] In that paper I showed, conclusively I think, that a lump of matter far out in inter-stellar space could not possibly fall to absolute zero of temperature by radiation of all its heat, as commonly supposed, but would soon acquire and then maintain the "temperature of space" which I estimated to be something like 50° to 100° above absolute zero.

Above the gamma rays there are about six octaves which have not yet been explored experimentally. Then we come to the cosmic rays, so ably demonstrated and studied by Dr. Millikan. These cover considerably less than one octave, and their mean frequency is about five thousand million million million waves per second. This is ten million times greater frequency than light waves possess; and yet there can be no doubt that cosmic rays are ether waves like all the rest. As might be expected, cosmic waves, on account of their very much higher frequency (shorter wave-length), have far greater penetrating power than the highest-frequency X-rays; in fact, about 300 times greater, as they pass through six feet of lead.

[1] *Proc. Am. Phil. Soc.*, Vol. LXVI, 1927.

Starting considerably above cosmic rays in the chart, I have drawn a long bracket with indeterminate ends. Somewhere in this region lie the isotropic ether waves of gravitation, probably having considerable range of frequency. The enormous frequency of these waves enables them to pass freely through all kinds of matter without obstruction except that concerned in gravitation.

Probably most of the vast intrinsic wave energy of the ether lies in the region of the gravitation waves.

Until about a year and a half ago, we had no experimental evidence of the gravitation waves other than gravitation itself. But gravitation is a most impressive demonstration of the ether waves which cause it, and of the very great energy embodied in them. As illustrating both points, I call attention to Lord Kelvin's graphic word-picture of collision of two large astronomical bodies under the influence of their mutual gravitational attraction, which I have quoted in my 1914 paper,[2] and my 1926 paper.[4] As another illustration of the enormous differential ether-wave *push* of astronomical bodies toward each other, let us consider the case of the earth and moon. The urge toward each other is commonly called gravitational attraction, which is only another way of looking at it. If this attraction were absent, and the moon were held in her orbit by a weightless steel cable, the cable would need to be about 500 miles in diameter to stand the strain. Between the earth and sun, the cable must be about 6,000 miles in diameter. And the attraction (push toward each other) of the components of some double stars must be thousands of times greater than this.

Obviously, the ether waves of gravitation, and the other classes of waves we have discussed, must be permanent attributes of the ether; they cannot escape either from boundless or bounded space. They must fill all space; and we may therefore regard gravitation as a property of space, because wherever there are two or more particles or bodies of matter, however small or large, however near or distant, they are urged toward each other by the ever-present isotropic ether waves of gravitation.

Very high up in the chart I have tentatively drawn the line marked "Quanta waves or rays," indicating a frequency of 6.554×10^{27}.

Experimental Evidence of the Ether Waves of Gravitation

A year ago I had the honor of presenting a paper under the title "Correlation of Continual Generation of Heat in Some Substances, and Impairment of Their Gravitational Acceleration."[1]

This division of the present paper is a continuation of last year's paper; and to save the reader the bother of looking up that paper and its several references, I shall quote very freely from it and prior papers.

The third "Discussion"[4] (1926) contains in its title "Some Experimental Evidence Supporting Theory; Continual Generation of Heat in Some Igneous Rocks and Minerals. Relation of this to the Internal Heat of the Earth and Presumably of the Sun." Quoting from this paper, "Gravitation Waves and Heat":

"Heat is often defined as an agitation of atoms and molecules of matter, and measured by the total kinetic energy of such agitation. The agitation consists partly in internal vibrations of the elastic atoms and molecules and spinning about their various axes, and partly in a very rapid translatory motion among themselves. Thus they are supposed to dart about in every conceivable direction, constantly colliding with each other and rebounding or glancing in new directions. The kinetic energy of this translatory motion constitutes *sensible* heat (not total heat) and is the measure of *temperature*. Anything (such as absorbed radiation) which stimulates the internal vibration of atoms or molecules likewise increases their translatory velocities by the increased violence of rebound after collision, and thus increases their temperature; and *vice versa*.

"All the above is known to be true of gases and vapors (Kinetic theory of gases), and is generally believed to be true of liquids and solids.

"The '*mean* free path' and the '*mean* velocity' between collisions of the molecules of many gases under stated conditions have been computed. But it has also been shown mathematically that the higher and lower velocities, and the longer and shorter paths,

[1] *Proc. Am. Phil. Soc.*, Vol. LXVII, No. 2, 1928.

differ greatly from the means, and may in each respect vary twenty or more times in amount. Doubtless this is true also of liquids and solids.

"From the fortuitously wide variation in velocities and free paths of the billions of vibrating atoms or molecules in their heterogeneous movement, it follows that collision frequencies must also vary greatly, from instant to instant, everywhere in a body of matter.

"Probably the postulated gravitation waves are not confined to one frequency, but have a wide range of frequencies as do the well-known X-rays.

"With the foregoing in mind it is easily conceivable that some kinds of matter may have atoms or simple molecules or complex molecules of occasional vibration frequency corresponding with some gravitation wave frequency, whereby fortuitous resonance can, for brief instants, be established at various points. This would result in a slight increase of vibrational activity and a cumulative rise of general temperature.

"A body of such matter, with some thermal insulation, would become and remain permanently warmer than a neighboring body similarly circumstanced, but not endowed, or less endowed with the permissive heat-generating quality."

A carefully designed calorimeter is illustrated and described in the paper (1926), and details of many experiments given. These resulted in the discovery that some rocks and minerals did generate an easily observable amount of heat.

In April, 1927 I presented another paper on "Persistent Generation of Heat in Some Rocks and Minerals." [1] This is a continuation of the 1926 paper. It describes a new and different calorimeter, built in the spring of 1926, and since known as the "Ice Calorimeter." It has been in almost continuous use down to the present time (April, 1928) and has proved very satisfactory. With this calorimeter it has been found that some of the natural heat-generating materials, and some of the artificial silicates hereafter described, have retained their heat-generating activity unimpaired; and none of these substances is more than minutely radioactive. Quoting from the 1927 paper:

"It is notable that all the materials which appear to be endowed with persistent heat generating activity are complex silicates."

There follows a description of the preparation, in the wet way, of many complex silicates, and their preliminary testing for heat generation. A silicate of the protoxides of nickel and cobalt showed

[1] *Proc. Am. Phil. Soc.*, Vol. LXVI, 1927.

very large activity, larger than either silicate alone; and this now appears to be permanent. Nickel and cobalt are almost identical in atomic weight, and differ but one unit in atomic number. Quoting again from the 1927 paper:

"In the absence, at present, of other explanation, it is thought that persistent heat generation in some rocks and minerals is due to isotropic ether waves of great penetration; very great indeed, if the generation goes on in the interior of the sun and planets as it does at the surface of the earth." Quoting now from the 1928 paper: [6]

"It is now believed that the class of isotropic ether waves postulated as the cause of persistent generation of heat in some substances, is the same class, perhaps of very wide range of frequency, postulated as the cause of gravitation.

"Conversion into heat of some of the energy of the gravitation ether-waves, however little, might be expected to impair to some extent the falling velocity of a heat generating substance; *and all such substances thus far tested have clearly shown impairment.*

"I have yet found no exception to this remarkable phenomenon, though I have already tested many natural and artificial minerals. Substances which have shown no generation of heat in the calorimeters show no impairment of their falling velocity when compared with lead. Substances exhibiting small, moderate or large generation of heat have shown comparatively small, moderate or large impairment of their gravitational acceleration.

"In making the above indicated comparisons of falling velocities I have largely used the method and apparatus described and illustrated in my 1923 paper on 'Some New Experiments in Gravitation.'" [1] (See also 1924 paper of same title.) [2]

"Two aluminum containers are used, alike in size, shape, weight and smoothness of surface, and dropped *simultaneously*, side by side, through exactly the same distance (about 122 cm.).

"Each container, at the end of its journey, breaks an electric circuit. But the breaks of both containers are in series in the same circuit, so that the break which occurs first produces a bright spark, while the belated break gives no spark because its circuit is already open.

"When the containers are equally loaded with the same metal, there is no visible spark at either break, or a very feeble spark at one or the other indifferently. But when they are equally loaded with certain different metals, one container persistently produces a

[1] *Proc. Am. Phil. Soc.*, Vol. LXII, No. 3, 1923.
[2] *Proc. Am. Phil. Soc.*, Vol. LXIII, No. 1, 1924.

bright spark, though the containers are always reversed in position for each trial. From this it seems clear that the container giving the spark falls a little faster than the other. This sparking condition is clearly manifested when the faster container reaches the end of its free path as little as .0125 mm. (.0005 inch) in advance of its neighbor.

"The 1923 paper also describes how approximate quantitative measurements are made. These are very tedious, especially when falling velocity differences are large.

"To facilitate estimation of the larger falling velocity differences I am perfecting a photographic method of observation. After falling about 110 cm. the small lower ends of the containers are photographed in silhouette against a white background having many horizontal black lines, and illuminated by a very bright electric spark."

Then follows several pages of text, with figure and plates, describing the apparatus and its operation, too lengthy to quote here. Resuming quotation from last year's paper (1928):

"The camera lens is located about 37 cm. in front of the white surface, and the photographic plate about an equal distance behind the lens; so that the image is about equal in size to parts photographed.

"The plate holder moves vertically in guides, and rests on a pin in one of eight equally spaced holes 1.6 cm. apart in the back-board of the camera. This back-board has a horizontal opening 1.4 cm. wide, which limits the exposed portion of the plate to a strip of this width. Thus eight pictures of the falling container tips are made on one plate. The containers are reversed in right and left position after each exposure.

"Plate III shows such a series of photographs. Each container weighed approximately 30.6 grams. One was marked with a white spot on its top for identification. This one, lettered S on the plate, was filled with silicate of nickel and cobalt, which weighed 13.6 grams, or about 30.8 per cent of the total weight of the loaded container. The unmarked container was loaded with lead sawdust, held tightly in the lower end by a short closely fitting cork above it, until it very closely equaled the marked container in weight.

"Each of the eight photographs on the plate, when magnified, clearly shows the S container (Silicate) slower than its companion. Six more similar plates have been made with the same loaded containers, and all show the same effect. It will be noticed that the amount of retardation of the S container varies considerably in the eight exposures of Plate III. This was principally due to small lateral air currents in the room which acted unequally on the two containers when one shielded the other; as was demonstrated with another plate by purposely increasing the lateral air currents. I shall eliminate lateral air currents in future work.

"Of course I tried exchange of loads in the containers, but without observably affecting the result; the container holding the silicate was always slow.

"The observed retardation of the silicate container must be due to impaired gravitational acceleration of the silicate as compared with the lead sawdust in the other container; and as the silicate constitutes only 30.8 per cent of the total mass undergoing acceleration, we must multiply the observed retardation by 3.25 to find the full impairment of the silicate alone.

"In the apparatus as set up, the centers of the container tips are about 1.6 cm. in front of the lined background; hence tips and lines cannot both be sharply in focus of the camera lens. In Plate III the focal plane of the camera was about half way between the tips and the lines. Sharpness of lowest part of the curve of the tips was very greatly enhanced by permanently covering all of the camera lens except a horizontal strip 2 mm. wide across its center.

"The comparison lines in Plate III are spaced one mm. apart between centers. I am installing another white background with very much finer lines spaced only half a mm. apart, and far better adapted to micrometer measurement of container tip differences of level.

"The Bureau of Standards, with a calorimeter of its own designing, is working with some of the heat-generating substances for the purpose of checking my findings."

Since writing the 1928 paper I have continued work on the fascinating subject of "Correlation of continual generation of heat in some substances and impairment of their gravitational acceleration." These phenomena appear to be related as cause and effect. I have gathered considerable new evidence, all affirmative, so that I now feel justified in dismissing doubt.

In the quest for more evidence, however, I have reversed the order of procedure; *i.e.*, instead of hunting more or less at random, for new substances exhibiting generation of heat in the calorimeters, which is a very slow and tedious process, I have first tested many new substances for impaired gravitational acceleration, which is comparatively rapid and easy.

In these tests I have made more than fifty new plates, and feel well rewarded for the labor.

In my former experiments it had appeared that silicates of the iron group of metals exhibited much greater impairment of acceleration than silicates and compounds of the metals of lower atomic weight. So I chose silicates and other compounds of metals of still higher atomic weight, viz., Barium, Lead and Bismuth as most promising materials to work with.

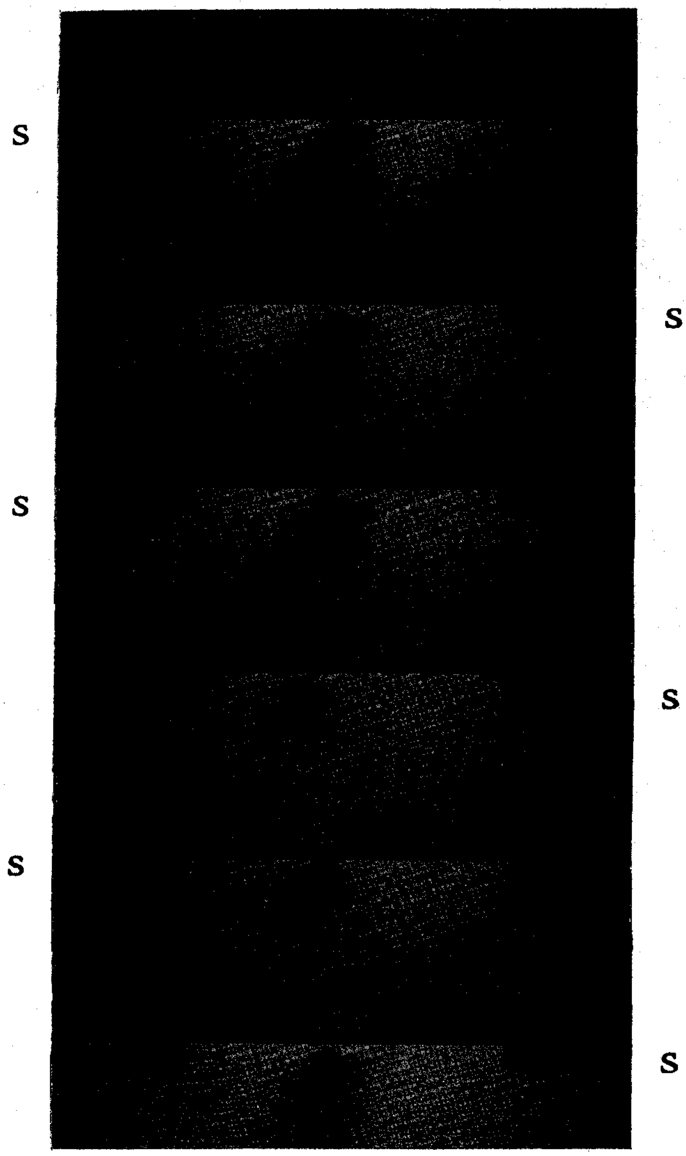
In all the artificial silicates there was some sodium silicate. Lead silicate gave a moderate effect, but after ignition none. Bismuth silicate behaved in the same way. Lead acetate gave a moderate effect.

The Barium compounds were found very interesting, and were more fully investigated. Barium Hydroxide, $Ba(OH)_2$, $8H_2O$ gave rather large effect, but required lining of the container on account of its powerful corrosive action on metallic aluminum. BaO (anhydrous); effect moderate. BaO, $8H_2O$; effect small but certain. $BaCl_2$, $2H_2O$; effect small. $BaBr_2$, $2H_2O$; effect very small if any. $BaSO_4$; effect very moderate. Ba_3, $(PO_4)_2$; effect small. $Ba(SCN)_2$, $2H_2O$; effect very small if any.

The Barium Aluminates were the most interesting of all the compounds examined. Three grades were prepared: $(BaO)_2Al_2O_3$, BaO, Al_2O_3 and $BaO(Al_2O_3)_2$. All, after air drying to constant weight, lost several per cent of hydroscopic moisture when dried at 100° C. and several more per cent of combined water when gently ignited. After ignition they were but very slightly hygroscopic. The BaO, Al_2O_3, dried at 100° C., gave largest effect; but after ignition the effect was somewhat reduced.

Plate I shows the impairment of gravitational acceleration in the BaO, Al_2O_3, not ignited, as compared with lead in the usual way. The upper two of the usual eight photographic strips are omitted, in order to permit enlargement of the remaining six strips about fifty per cent. The black lines on the white background against which the lower tips of the two falling containers are photographed, are spaced exactly half

PLATE I



a millimeter apart between centers, and are as fine as it was found practicable to make them. As before explained, neither the lines nor the tips of the rapidly falling containers are sharply in focus of the camera lens. The tip of the container holding the Barium Aluminate is marked S (slow) on the plate; and the containers were reversed in position after each dropping as indicated. As easily seen on the plate, the S container is unevenly slow in the six photographs, and even very slightly fast in the first. This unevenness is attributable to variation in the exceedingly slight friction of the containers in their guiding tubes during the first millimeter of their fall. The containers are perfectly free after that.

For accurate measurement of falling velocity differences of the containers on all plates, I have used a binocular microscope of low magnifying power, having a very large stage provided with a high-precision micrometer specially designed and built for this purpose.

In finding the average impairment of gravitational acceleration of the S container in the six photographs of Plate 1, all were measured with the micrometer, the five affirmative values were added together, the slight negative value of the first one subtracted from the sum, and the remainder divided by six. This gave the mean slowness of the S container = .099 mm., say one tenth of a millimeter. This is one part in eleven thousand of the distance fallen (110 cm.). But the Barium Aluminate constituted only 40.3 per cent of the total weight of the loaded container. Hence, impairment of falling velocity of the Barium Aluminate alone, as compared with equal weight of lead in the other container, was one part in about 4450. When a companion plate was made with the container loads exchanged (as customary in all tests), slowness of the Barium Aluminate was found closely the same.

Of the several compounds described and tested for impairment of falling velocity, only two have been tested in the ice calorimeter for continual generation of heat. Barium Sulphate, the first of these, was chosen because of its undoubted stability, although it had shown but very moderate impairment of falling velocity. It exhibited very moderate but steady and satisfactory generation of heat during a long run in the calorimeter. The second calorimeter test was made with Barium Aluminate like that used for Plate I; but after preparation it was only air dried at room temperature, to avoid any instability that might arise from hot-air drying, or ignition. The specimen was prepared about two months ago, and has been in the calorimeter during the last six weeks, where it continues to show rather large and steady generation of heat. It appears to be quite stable.

More than a year ago the Bureau of Standards very kindly offered to repeat some of my experiments on "continual generation of heat in some substances." A special ice calorimeter, quite different from mine, was designed and built for the purpose. After much time spent in perfecting and calibrating the calorimeter, a specimen of the air-dried Sandusky clay described in some of my earlier papers, was tested during the last few months; and I have very recently received official announcement from the Bureau in confirmation of my finding that this substance does continually generate a measurable amount of heat. The Bureau is about to commence testing the comparatively very active Nickel-Cobalt Silicate described in my last two papers.

Correlation of continual generation of heat in some substances and impairment of their gravitational acceleration, is regarded as very strong evidence in support of the kinetic theory of gravitation; and we seem now well on the way of finding out something definite about the nature of gravitation, which has been by far the greatest of all outstanding physical problems.

Cleveland, April, 1929.