Dependence of Gravitational Action on Chemical Composition: New Series of Experiments

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My earlier experimental research on this subject was published in the journal *Apeiron*, vol. 4 N° 1, Jan. 1997, "Simple Experiments to Test the Dependence of Gravitational Action on Chemical Composition." The results show a variation in weight difference in the order of 10^{-5} between two spherical samples, Lead and Aluminium, measured in Ravenna (sea level) and on the top of mount Marmolada, on the Dolomites (at a height of 3260 metres). For this new series of experiments new samples were created in Lead, Aluminium, Gold, Silver, Bronze, Brass-Water and Brass-Sand, of different shape, weight and volume in comparison with the two used in the earlier experiment. Weighing also was carried out in different places: Torino (180 metres) and Plateau Rosà (3480 metres). The results substantially confirm those mentioned above: in violation of the Weak Equivalence Principle, the relationship between the weights of the two examples is different in different locations. As regards the setting up of the experiment, it was the same as that of the published one to which reference may be made for further clarification.

Introduction

This experiment is part of that class of experiments (composition-dependent experiments) aimed at direct verification of the Weak Equivalence Principle. The principle of the experiment is as follows: samples of different chemical composition with approximately the same mass and volume are weighed in different locations at different heights. In accordance with the WEP, the relationship between the weights of two samples measured in location "A" is strictly identical when measured in any other location "B" since it is equivalent to the relationship between the masses.

$$w_i(A) = m_i g(A) \Rightarrow \frac{w_1}{w_2}(A) = \frac{w_1}{w_2}(B) \Leftrightarrow \frac{w_1}{w_2}(A) - \frac{w_1}{w_2}(B) = 0$$

Dependence of g (acceleration of gravity) on the location refers in particular (but not exclusively) to height; in other words one substantially considers $g = g(r)$.

Using samples of identical volume would eliminate the problem of different fluid pressure. In fact it was sought to reduce the problem to a minimum, and in any case the final results were corrected to take account of volume differences among the samples. It is clear that a valid alternative would be to carry out weighing in vacuum or in a controlled atmosphere.

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Samples

The seven new samples are cylinders. The five metallic samples are externally identical with a nominal diameter of 16 mm, nominal height 55 mm and nominal weight 29 grams. The Aluminium sample is solid while the others are hollow. The last two are hollow, made of chromium-plated brass foil, both with a nominal weight of 16 grams. The first contains nominal 20 grams of marine water, the second nominal 20 grams of dried siliceous sand. Depression seal of the hollow samples was inspection tested with the procedure described in the article mentioned above.

The volumes of the samples in the following table were measured at the Istituto Colonnetti of Torino with a hydrostatic weighing method repeated at least three times. This method consists in weighing the object in question (in accordance with a direct reading scheme) both in air and immersed in a reference liquid (bi-distilled water) of known density at the taring temperature.

The volumes of the spherical samples used in the earlier experiment, measured with the same method, are shown below.

New samples (cylinders)

Sample	Temp. ± 0.5 °C	Volume (cm^3)	Uncertainty (cm^3)
Gold	20.3	11.562	.004
Silver	20.5	11.615	.002
Lead	20.9	11.201	.002
Bronze	20.5	10.958	.003
Aluminium	20.2	10.944	.001
Brass-Water	21.0	23.785	.005
Brass-Sand	21.0	23.547	.005

Previous samples (spheres)

Aluminium	21.1	66.645	.002
Lead	21.4	66.656	.003

Setup

The new samples were weighed in Torino at the Istituto Cosmogeofisico (at a height of 180 metres) and the following day at Plateau Rosà, above Cervinia (3480 metres, about 340 kilometres west from mount Marmolada) in another of the Institute's laboratories. The geophysicist Dr. Alberto Romero of the Istituto Cosmogeofisico of Torino took an active part in the two series of weighings. An analytical balance was used as a dynamometer, thus omitting calibration after movement. The balance used was a Mettler mod. AE240 with 0.01mg sensitivity in the option of a max. capacity of 40 grams. The samples were weighed in sequence for ten consecutive sequences. For the necessary stabilisation the balance was switched on at least two hours prior to the operations.

Experimental Results

What follows is a typical series of successive weightings of one sample:

Lead
29.62004
29.62006
29.61993
29.61998
29.61996
29.62001
29.62000
29.62002
29.62000
29.61998

Average: 29.62199(8) $$\overline{w} = \frac{1}{N}\sum_{k=1}^{N} w_k$$

Standard Deviation: .000038 $$s_W = \sqrt{\frac{\sum_{k=1}^{N}\left(w_k - \overline{w}\right)^2}{N-1}}$$

Standard Deviation of the Average: .000012 $$s_{\overline{w}} = \frac{s_w}{\sqrt{N}}$$

The following table shows the average values calculated, Standard Deviation and Standard Deviation of the Average on the ten weightings of each sample. The table shows the average temperatures during measuring operations. However, the influence of temperature on measurement is wholly irrelevant in this limit of few grades of difference.

Sample	**Torino, 180m asl, (22 °C) G**			**Plateau Rosà, 3480m asl, (19 °C) g**		
	w (average)	**SD**	**SDA**	**w** (average)	**SD**	**SDA**
Bronze	29.568961	.000020	.000006	29.553100	.000052	.000017
Lead	29.635987	.000049	.000016	29.619998	.000038	.000012
Aluminium	29.646799	.000025	.000008	29.630950	.000045	.000014
Gold	29.638833	.000021	.000007	29.623199	.000026	.000008
Silver	29.621274	.000039	.000012	29.605629	.000026	.000008
Brass-Water	36.557286	.000034	.000010	36.541208	.000048	.000015
Brass-Sand	36.557263	.000028	.000009	36.541227	.000025	.000008

Subsequently the corrections relating to fluid pressure were calculated, adding to the weight of each sample the local air density multiplied by the volume of the sample itself.

$$\overline{w}_{i(correct)} = \overline{w}_i + d_{air}\cdot V_i = \overline{w}_i + w_{air}$$

Humphrey's table was referred to for air density volumes, some values of which are shown, followed by the interpolated values.

Elevation M	**Density dry air ´10^{-3} g/cm^3**
0	1.223
500	1.157
1000	1.100
1500	1.043
2000	.990
2500	.942
3000	.892
4000	.803
Interpolated values:	
180	1.199
3480	.849

Linear interpolation error is estimated at a max. of 0.2%. Error was therefore calculated on the corrected weights taking the maximum of SDA (w) values and average values for the other sizes. The errors were added in quadrature. The following table shows the corrected weight values, w_c:

	$w_c \pm 3\times10^{-5}$g		$\frac{w_c(\text{Torino})}{w_c(\text{Plat. Rosà})}$	$\frac{w_c \ \text{Lead}}{w_c \ (...)} \pm 1.4\times10^{-6}$	
	Torino	Plateau Rosà	$\pm 1.4\times10^{-6}$ *)	Torino	Plateau Rosà
Lead	**29.64942**	**29.62951**	1.0006720	1	1
Brass-Water	36.58580	36.56140	1.0006674	.8104078	.8104041
Bronze	29.58210	29.56240	1.0006664	1.0022757	1.0022701
Silver	29.63520	29.61549	1.0006655	1.0004798	1.0004734
Brass-Sand	36.58550	36.56121	1.0006644	.8104145	.8104084
Aluminium	**29.65992**	**29.64024**	1.0006640	**.9996460**	**.9996380**
Gold	29.65269	29.63302	1.0006638	.9985427	.9998816

*)This ratio theoretically represents *g*(Torino)/*g*(Plateau Rosà).
Note: the values are referred to the Lead sample because it presents the highest value of the ratio wc(T.)/wc(P.R.).

The complete table of the final results is shown in the last section.

Comparison with earlier experiment

Air density at sea level: 0.001223 g/cm³ Air density at 3260 metres: 0.000869 g/cm³
The error shown in the table is the sensitivity of the balance: the standard deviation of the average is approximately half.

Location	Lead		Aluminium	
	w ±0.0001g	w_c ±0.0001g	w ±0.0001g	w_c ±0.0001g
Ravenna	180.8833	180.9648	180.8915	180.9730
Marmolada, Punta Rocca	180.8120	180.8699	180.8216	180.8795

Location	Lead/Aluminium ± 0.000001
Ravenna	.999955
Marmolada, Punta Rocca	.999947

	Lead	Aluminium
$\dfrac{w(Ravenna)}{w(Marmolada)}$ ± 0.000001	1.000394	1.000387

As may be easily calculated, correction for the difference in volume of the two samples is, in this case, wholly superfluous.

It was noted in the introduction that, in accordance with the Weak Equivalence Principle

$$\frac{w_{Pb}}{w_{Al}}(A)-\frac{w_{Pb}}{w_{Al}}(B)=0$$

Comparing the two experiments it may be seen, rather, that:

$$\frac{w_{Pb}}{w_{Al}}(A)-\frac{w_{Pb}}{w_{Al}}(B)\neq 0$$

In some other previous experiments, performed in locations at different heights above sea level, it was noted that this difference increases with height.

Keeping in mind that the height difference between the locations is approximately the same, we find that:

$$\frac{w_{Pb}}{w_{Al}}(\text{Ravenna})-\frac{w_{Pb}}{w_{Al}}(Marmolada)=\frac{w_{Pb}}{w_{Al}}(Torino)-\frac{w_{Pb}}{w_{Al}}(Plateau\ Rosà)$$

or precisely $(8\pm 1)\times 10^{-6}=(8\pm 2)\times 10^{-6}$

Conclusions

The following table shows all the combinations of the pairs of samples. The values represents

$$\left(\frac{\mathrm{w_i}}{\mathrm{w_k}}(\text{Torino})-\frac{\mathrm{w_i}}{\mathrm{w_k}}(\text{Plateau Rosà})\pm 2\right)\times 10^{-6}$$

Lead/ Aluminium	Lead/ Bronze	Lead/ Gold	Lead/ Silver	Lead/ Br.-Water	Lead/ Brass-Sand	Br.-Water/ Aluminium
8	6	8	6	4	6	4

Br.-Water/ Bronze	Br.-Water/ Gold	Br.-Water/ Silver	Br.-Water/ Brass-Sand	Bronze/ Aluminium	Bronze/ Gold	Bronze/ Silver
1	4	2	3	2	3	1

Bronze/ Brass-Sand	Silver/ Aluminium	Silver/ Gold	Silver/ Brass-Sand	Brass-Sand/ Aluminium	Brass-Sand/ Gold	Gold/ Aluminium
2	2	2	1	0	1	0

Having altered various parameters with regard to the earlier experiment, full confirmation of those results was obtained: dependence of gravitational action on chemical composition.

Note added in proof

After submission of this paper, the editors suggested to mention and take into account in a next series of experiments of the following objections expressed by a referee:

1. In the article it is not pointed out the error of the scale, but only its sensibility. In principle the error of a scale generally surpasses considerably its sensibility.

2. Verification has not been made if the concrete distribution of the obtained results is normal, but formulas are used that correspond to a normal distribution.
3. In the article the author considers the terms "SDA" (standard deviation of the average) and "error." In no part it is mentioned with what value of the probability of trust one works. For an experiment of this type it should not be smaller than $P = 0.999$. For this probability of trust and the one numbers of measures $n = 10$ the coefficient of Student is t (0.999; 10) = 4.587, and the one should take into account it.
4. The t-criterion has not been used to compare the medium values of both magnitudes.
5. The density of the air has not been measured, but it has taken from a table. But the density of the air depends on the real pressure, the real humidity and the real temperature that have not been measured.

The referee also suggested " to obtain information from metrological centres in Italy where metrological experiments are carried out. The measurements for both altitudes should be executed under same conditions (pressure, temperature, humidity etc.). It is necessary to increase the number of measurements considerably (up to a hundred) for each case. It is necessary to apply appropriate statistical processing."

Response to the observations of the referee

The referee presented his observations point by point whereas I prefer to respond in a general way. In the last table of point 4 the balance error shown is exactly $\pm 3\times 10^{-5}$ g. The differences in weight between Turin and Plateau Rosa are much higher than the measuring instrument error mentioned above. They are statistically substantial.

The differences in temperature between the two ambiences of the experiments are shown in the article. These differences however do not significantly affect the weights of the various samples.

Regarding air density, it should be noted that the samples were constructed having not only the same nominal weights and volumes but in the article the dimensions are also shown. It follows that the first five and the last two samples present the same external surface area to the effect of air density. Therefore the conspicuous differences in the experimental results do not depend on air density but depend rather on chemical composition.

Finally, the referee advised us to get in touch with the Italian Metrological Centres. This has been done. The 'Colonnetti' Metrological Institute of Turin obtained for me the authorisation of the CNR Cosmogeofisico Institute of Turin to go up to Plateau Rosa. They gave me advice for the experiment concerning the number of weighings to make, ten for each of the seven samples (to be done in rotation) both at Turin and the refuge at the top of Plateau Rosa. The total number of weighings was 140.

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