Proceedings of the Iowa Academy of Science

Volume 15 | Annual Issue Article 24

1908

Some Peculiarities in the Elastic Properties of Certain Substances

K. E. Guthe

SOME PECULIARITIES IN THE ELASTIC PROPERTIES OF CERTAIN SUBSTANCES.

BY K. E. GUTHE.

All solids deviate more or less from the theoretical perfectly elastic body and though many experiments have been undertaken in order to explain these deviations, we can hardly claim that any of the numerous theories proposed by the different investigators has yet cleared up the intricate relations involved.

The best known of these deviations is the so-called elastic after effect. It was first discovered in silk fibers in 1835 by W. Weber and consists in a lagging of the establishment or disappearance of a strain behind a distorting force. Thus if we twist a wire at one end while the other end is kept fixed, then upon releasing the wire there will be at first a rapid return towards the original shape, followed by a slower change in the same sense, extending sometimes over considerable time. The longer the original deformation has lasted the stronger will be the after effect. Of course the deformation is supposed to remain always below the value at which a permanent set occurs, so that after a sufficiently long time the return to the original condition is complete. Many experimental and theoretical investigations have led scientists to believe that elastic after effect may be considered as a kind of viscosity. It must, however, be remembered that it differs in its nature from the viscosity of fluids because in the latter case there is no tendency to return to the original shape after the stress is removed.

The elastic after effect is especially apparent in soft metal wires, while the same wires hardened show it to a much smaller degree. Quartz fibres, carbon filaments and wires of hardened steel, phosphor bronze and platinum-iridium have very small elastic after effects.

Another deviation from the demands of the theory has received the name "elastic fatigue." Lord Kelvin[1] observed that a wire which had been kept under torsional vibrations for some time has a larger period of vibration and a larger logarithmic decrement than a wire which has been at rest. J. O. Thompson[2] has later demonstrated that as long as the amplitude and temperature remain constant there is no such change, even if the wire is kept vibrating for days. It is, however, a well known fact that when the amplitudes decrease from larger values to smaller the period, as well as the logarithmic decrement, decrease somewhat. So far only cases were known in which the variations of these quantities are quite small; in the course of some experiments with platinum-iridium wires which show almost no elastic after effect I found such remarkable

1. Kelvin, Math. and Phys. Papers, III, p. 22.
2. J. O. Thompson, Phys. Rev. VIII, p. 141.

deviations from the behaviour of ordinary wires that I decided to investigate the matter further.

The wires which carried at their lower end cylinders of Tobin bronze were suspended from the top and inside of a large hollow brass cylinder having a glass window at its lower end. The whole brass case could be rotated around a central pivot and thus the suspended cylinders set in vibrations. The glass window allowed the observation of a small mirror attached to the lower end of the vibrating system. The period was determined by chronographic records and the amplitudes by a telescope and scale placed at a distance of 100 centimeters from the mirror.

A platinum-iridium wire containing 25 per cent of iridium, when hardened by drawing a period of 6.7766 sec. with an amplitude of 5°, which decreased to 6.7745 sec. with an amplitude of 0.°5, while its logarithmic decrement decreased between the same amplitudes from 0.0012 to 0.00091. A still more surprising behaviour was found in a 40 per cent platinium-iridium wire whose period of vibration changed through the same range of amplitude from 12.060 sec. to 11.890 sec., while its decrement decreased from the enormous value of 0.012 to 0.0030.

The period, as well as the logarithmic decrement, are very nearly proportional to the amplitude, though the increase is slightly smaller than that of the amplitude. The decrease of amplitude between successive swings is very nearly proportional to the square of the preceding amplitude. Since such enormous variations have never before been observed in other wires, a great many observations were made, but in every case the same effect was found. In the following tables I have picked out at random a few of them and the values are plotted in figures 1 to 3.

TABLE I.
Forty per cent Platinum—Iridum Wire.
Moment of Inertia: 372.4.

Amplitudes, 1st, 5th, 9th, etc.	△ A	A^2	d	Double Period
48.7		2372		
42.5	6.2	1806	0.0133	14.700 sec.
37.9	4.6	1436	0.0121	14.620
34.0	3.9	1156	0.0114	14.565
30.7	3.3	942	0.0105	14,545
28.0	2.7	784	0.0099	14.525
25.6	2.4	655	0.0093	14.508
23.65	1.95	559	0.0084	14,497
21.95	1.7	482	0.0079	14.485
20.45	1.5	418	0.0076	14.475
19.10	1.35	365	0.0072	14.465
17.85	1.25	319	0.0068	14.455
16.88	1.02	283	0.0065	14.446
15.88	0.95	252	0.0062	14.439
15.02	0.86	226	0.0059	14.432
14.22	0.80	202	0.0056	14.426
13.55	0.67	184	0.0053	14.420
12.93	0.62	167	0.0053	14.415
12.30	0.63	151	0.0051	14.412
11.76	0.54	138	0.0048	14.408
11.27	0.49	127	0.0045	14.405
10.82	0.45	117	0.0045	14.402
10.38	0.44	108	0.0043	14.399
10.00	0.38	100	0.0041	14.396
9.62	0.38	93	0.0042	14.393
9.26	0.36	86	0.0041	14.390
8.22	0.34	80	0.0039	14.388
8.62	0.30	74	0.0038	14.386
8.33	0.29	69	0.0035	14,384
8.09	0.24	65	0.0034	14.383
7.82	0.27	61	0.0035	14.381
7.58	0.24	57	0.0034	14.380
7.34	0.24	54	0.0035	14.378
7.11	0.23	51	0.0034	14.377
6.90	0.21	48	0.0032	14.376
6.70	0.20	45	0.0032	14.375
6.50	0.20	42	0.0032	14.373
6.32	0.18	40	0.0029	14.372
6.16	0.16	38	0.0029	14.370
5.99	0.17	36	0.0029	14.368
5.84	0.15	34	0.0030	14.366
5.67	0.17	32	0.0028	14.364
5.54	0.13	31	0.0028	14.363
5.40	0.14	29	0.0026	14.361
5.26	0.14	28	0.0028	14,359
5.13	0.13	26	0.0028	14.358

TABLE II.
Forty per cent Platinum—Iridium Wire,
Moment of Inertia: 987.7.

Amplitudes, 1st, 5th, 9th, etc.	△ A	A^2	δ	Double Period
35.4		1253		
31.8	3.6	1011	0.0104	24.120
28.9	2. 9	835	0.0097	24.060
26.6	2.3	708	0.0091	24.020
24.45	2.15	598	0.0086	23.980
22.7	1.75	493	0.0080	23.965
21.1	1.6	445	0.0077	23.940
19.7	1.4	388	0.0074	23.925
18.4	1.3	339	0.0070	23.910
17.35	1.05	301	0.0066	23,898
16.3	1.05	266	0.0063	23.886
15.45	0.85	239	0.0058	23.874
14.65	0.80	215	0.0056	23.868
13.94	0.71	194	0.0054	23.856
13.27	0.67	176	0.0053	23.848
12.65	0.62	160	0.0050	23.840
12.10	0.55	146	0.0048	23,832
11.58	0.52	134	0.0046	23.826
11.12	0.46	124	0.0045	23.818
10.67	0.45	114	0.0043	23.812
10.27	0.40	115	0.0042	23.806
9.88	0.39	98	0.0042	23.800
9.49	0.39	90	0.0040	23.796
9.17	0.32	84	0.0038	23.793
8.86	0.31	78	0.0037	23.790
8.56	0.30	73	0.0036	23.787
8.29	0.27	69	0.0033	23.784
8.04	0.25	65	0.0033	23.782
7.8	0.24	61	0.0033	23.780

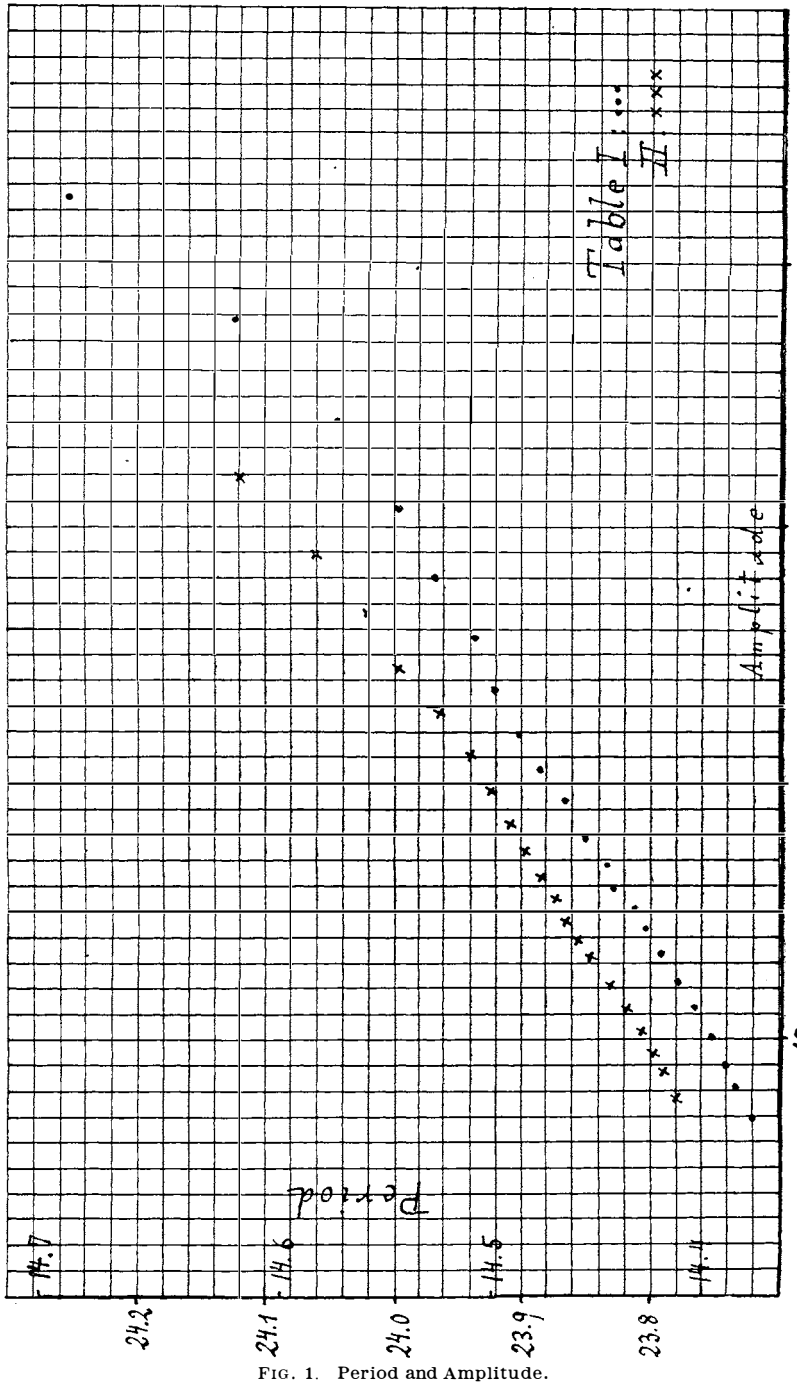


FIG. 1. Period and Amplitude.

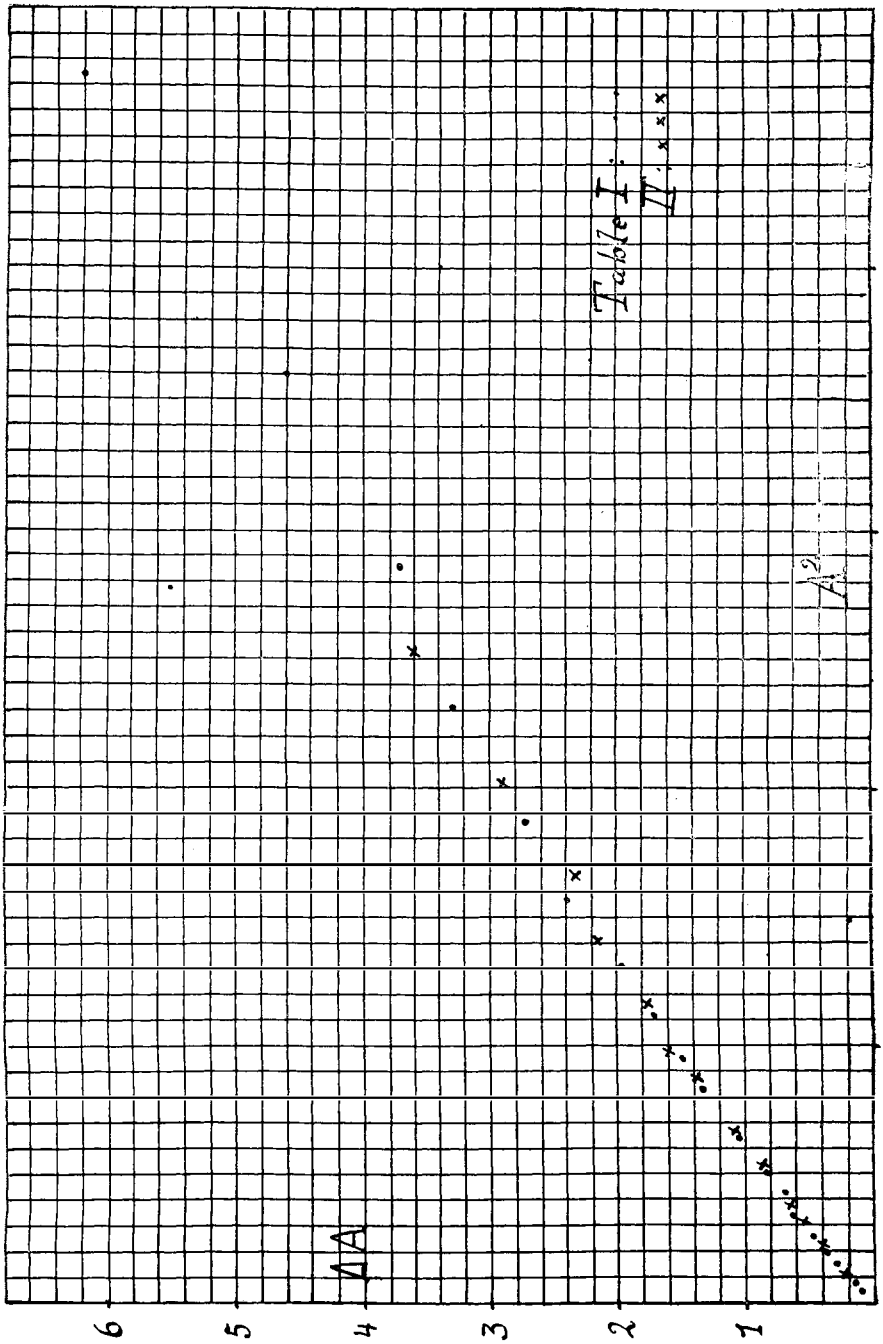
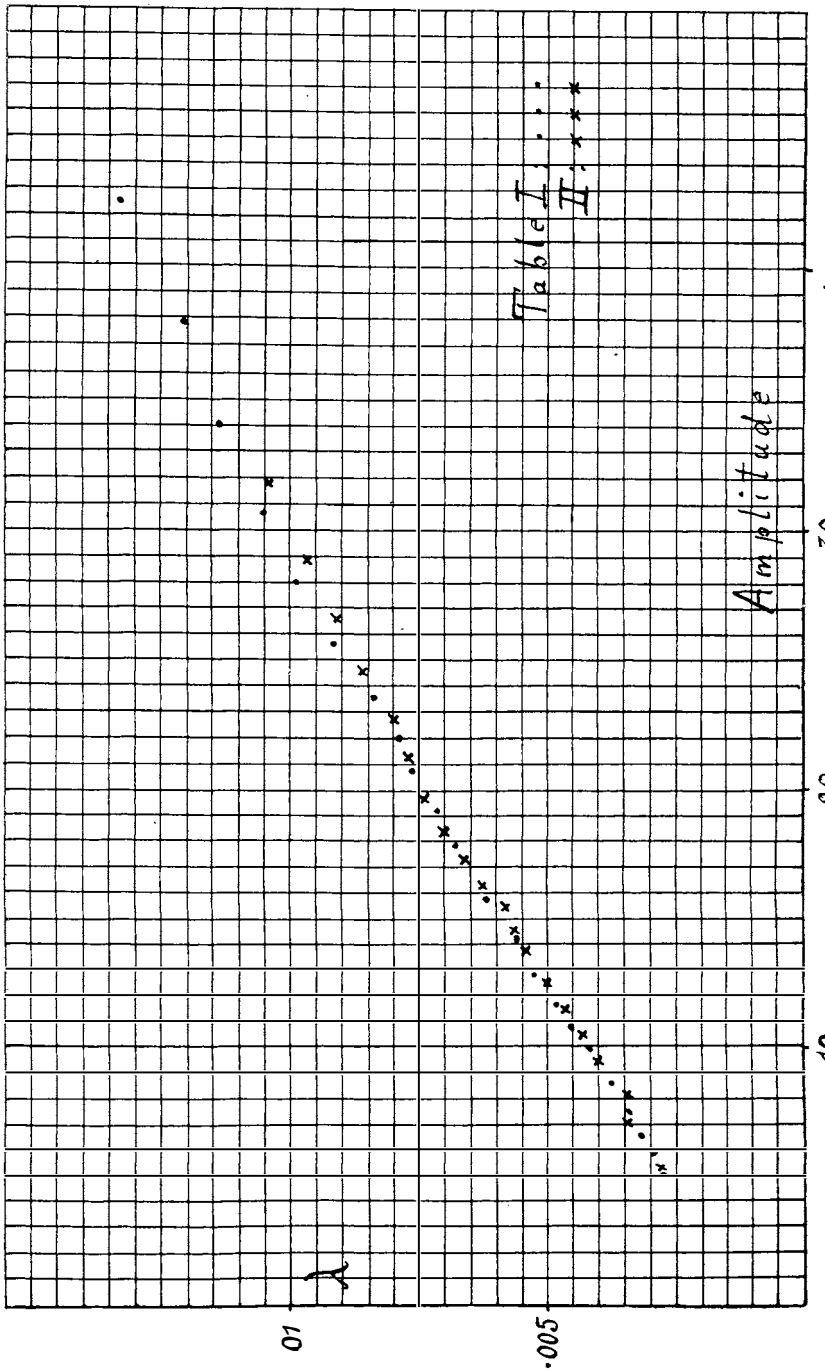


FIG. 2. Decrease in Amplitude and Square of Amplitude.



15 FIG. 3 Logarithmic Decrement and Amplitude.

Having thought at first that the property of iridium to absorb oxygen might be the reason for the observed anomalies, I experimented with the same wire under different pressures. The changes in the period and decrement were as large as before, even when the pressure was only 2.5 cm. A further decrease in pressure could not be obtained because the large brass case was not perfectly airtight.

The observations were repeated with a different moment of inertia suspended from the wire. The time of vibration was now only 7.274 sec. for the larger amplitude and decreased to 7.105 with the smaller amplitude. But most surprising of all was the fact that values of the logarithmic decrement when plotted as a function of the amplitude fell closely upon the same curve which was obtained with the larger period, and seems, therefore, to be independent of the velocity with which the system moves.

It made no difference whatever with how large an amplitude I started, whether or not the wire had been kept swinging for some time, and if it was swinging under atmospheric or decreased pressure; for the same amplitude always the same large logarithmic decrement was found.

The phenomenon which this wire exhibits in such an exceptional degree has usually been considered as closely connected with elastic after effect, but the fact that the wire shows almost no after effect when tested by the usual method seems to indicate that there is little or no connection between the two.

My first thought was that the wire did not follow Hooke's law and I therefore connected one of its ends rigidly to a steel wire of equal length and at the connecting point a small mirror was sealed to the wires. The lower end of the steel wire was securely fastened and the upper end of the platinum-iridium wire clamped in a torsion head. It was found that equal deflections of the mirror were produced by equal angular displacements of the torsion head. This shows that the wire followed Hooke's law within the limits of the experiment.

I am unable to explain at the present time the results obtained with the platinum-iridium wire, but hope to continue the investigation with wires of different length and diameter and possibly also with alloys of platinum with other rare metals.

While the elastic after effect may have some influence upon the rate of dissipation of energy in a wire in torsional vibrations, there can be no simple relation between the after effect and the logarithmic decrement, even in the case of ordinary wires, because frequently wires with smallest after effect show very large values for the decrement. I have shown this to be true in all cases. Drawn wires have a considerably larger logarithmic decrement than softer wires. I have made a large number of experiments on this point, using first hard drawn wires and repeating the experiments after the wires had been annealed by drawing them through the flame of a Bunsen burner. In every case the soft wires show the smaller decrement and the larger moment of torsion.

Thus copper wire, hard drawn, had a period of 5.780 sec. and a logarithmic decrement of 0.0057. After annealing its time of vibration with the same moment of inertia and at the same temperature was 5.702, decreasing with amplitude to 5.692, and the decrement had decreased to 0.0022, more than one-half.

New light has recently been thrown upon the physical process taking place during the drawing of a wire. Beilby[3] arrives by very interesting microscopic

3. Beilby, Nature, 76, p. 572, 1907.

investigations at the result that all crystalline substances can also exist in a noncrystalline or amorphous form and that these two forms are so distinct from each other that they must be regarded as definite allotropic modifications. Further he showed that in the pure ductile metals the crystalline state is actually the soft state, while the hardened metal is a complex structure built up of crystalline and noncrystalline substance. During the drawing some of the crystals pass into the amorphous state and during the sudden congealing after the removal of the pressure the crystals are bound into a rigid mass irrespective of any orientation. When this mass is heated to a temperature far below the melting point of the metal recrystallization of the amorphous part takes place and the wire becomes soft.

This theory explains many peculiarities of hard drawn wire. Gray and Mees and more recently Wassmuth have shown that the density of wires drawn under great pressure is smaller than before drawing. Applying this theory to the results discussed in this paper, we have to assume that the amorphous state has a smaller rigidity than the crystalline state and we must expect a larger logarithmic decrement in amorphous solids. If the elastic after effect is due to a slipping of crystals with respect to each other the after effect should become smaller when the crystals are closely surrounded by the amorphous mass.

To test these conclusions experiments were made with fused quartz and carbon filaments, both amorphous substances. The quartz fibre was very thin and 480 mm. long. The elastic after effect was very small, the time of vibration very constant and no decrease of the decrement with amplitude could be observed. The decrement was 0.000572, a value twice as large as was obtained with much thicker metallic wires.

The thin carbon filament, 20 cm. long, had the very large decrement of 0.00548, the amplitude decreasing in 176 swings to one-tenth of its original value. But the decrement remained perfectly constant.

A similar effect to that of hardening by drawing can be produced in a palladium wire if hydrogen is deposited upon it by electrolysis. With a palladium wire this treatment produced an increase of the decrement from 0.0006 to 0.003, while the period was decreased from 7.954 sec. to 7.778 sec. The absorption of hydrogen is considered as a solution of hydrogen in the metal and it is quite reasonable to suppose that the crystalline structure of the wire is greatly impaired by such a treatment. With the 25 per cent platinum-iridium wire mentioned above, annealing reduced the logarithmic decrement from 0.00124 to 0.000327 without showing any other noteworthy effects.

The same treatment failed, however, completely with the 40 per cent platinum-iridium wire. Thinking that perhaps the temperature of the Bunsen burner was too low to raise the wire to the point of recrystallization, I sent through the wire, not under tension, an electric current sufficiently large to heat it to bright yellow heat. The point of recrystallization was undoubtedly reached and the crystals must have arranged themselves in any imaginable way; for placing the wire again in the torsion apparatus I was unable to get any zero point at all, though the wire was kept in continuous vibration for two days in the hope to have the crystals fall in line. They absolutely refused to do so and during each attempt of making a measurement the zero point shifted at least 10 cm. over the scale in the direction in which the torsion had first been applied.

Then the wire was heated again by an electric current to red heat, but this time under a load which it was to carry in the torsional experiments. No higher temperature was attempted for fear that the wire might permanently stretch under the load. The zero point after this treatment was again quite steady, but at the same time all its former peculiarities reappeared.

Apparently the conditions under which the annealing of the wire takes place has a great influence upon the elastic properties of the wire, and in future experiments this point shall receive special attention.