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Certain Elastic Properties of Phosphor-Bronze Wires

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CERTAIN ELASTIC PROPERTIES OF PHOSPHOR-BRONZE WIRES.

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INTRODUCTION.

The work by Guthe[1], Guthe and Sieg[2], and Sieg[3], on platinum-iridium wires when used as suspensions for torsion pendulums, showed some remarkable elastic properties of that alloy. The principal one of these was the variation of the period with the amplitude of vibration. It was these studies that made it seem very desirable to test other alloys commonly used for suspensions, by a similar method.

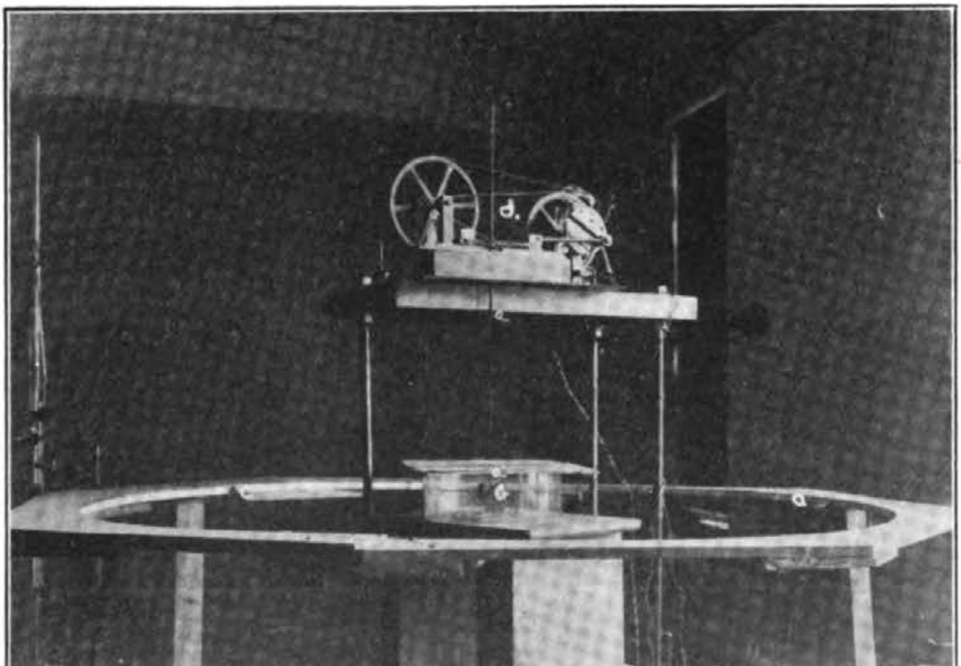

FIG. 27.

The wires employed in this research were of a phosphor-bronze alloy and represented thirteen successive drawings from an original sample. These ranged in diameter from .508 mm. to .100 mm. The wires were very kindly supplied by the American Electrical Works of Phillipsdale, Rhode Island.

[1]K. E. Guthe, Iowa Acad. Sci., 15, 1908, p. 147. Abst. in Phys. Rev., 26, p. 201, 1908.
[2]K. E. Guthe and L. P. Sieg, Phys. Rev., 30, 1910, p. 610.
[3]L. P. Sieg, Phys. Rev., 31, No. 4, 1910, p. 421.

THE PROBLEM.

The extensive use of phosphor-bronze wires as delicate suspensions, makes it very desirable to know intimately the elastic nature of this alloy. Some work by Professor Sieg and the writer in 1914, showed that the periods of the torsional vibrations were not constant but varied widely with different amplitudes.

The problem of this research was the verification of this elastic peculiarity and to prove that there is no justification for the use of these wires as delicate suspensions. New problems suggested themselves at once and some of these have been investigated to find out, if possible, more of the intimate nature of the alloy.

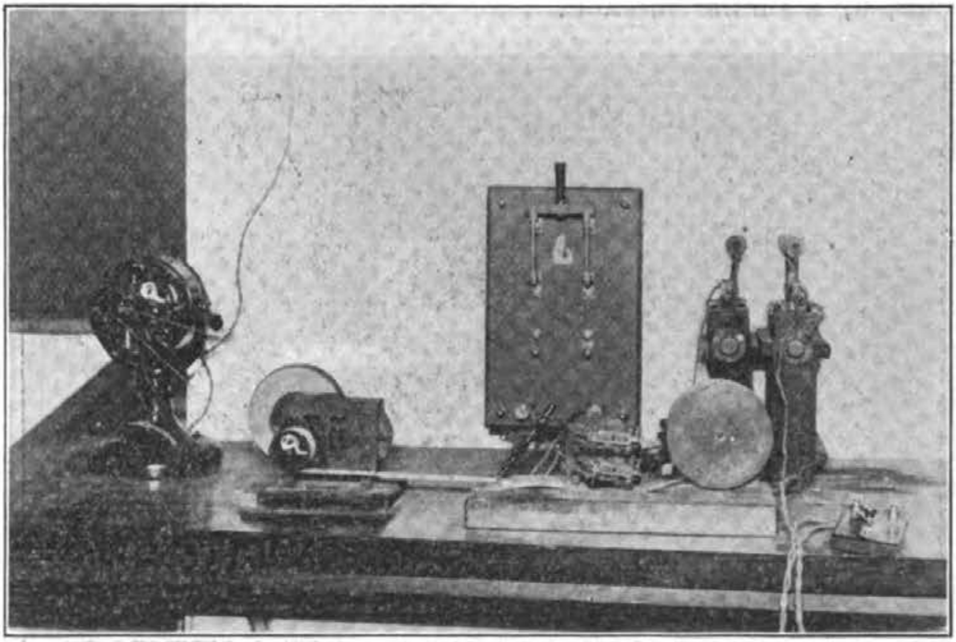

FIG. 28.

A preliminary report of certain of these experiments was given before the Iowa Academy of Science in the spring of 1915[4].

APPARATUS.

The apparatus is the same one which was employed and described by Sieg[5]. Figure 27 shows the complete apparatus with the exception of the arc which was used to illuminate the mirror, and figure 28 shows the timing device.

[4] Iowa Academy of Science, Vol. 22, 1915, p. 321.
[5] Loc. cit.

The length of the wire was usually 30 cms. and the initial twist in most cases was 10 degrees per cm. length of the suspension.

To make clear the method of observation, and the nature of the results, a sample of the data follows:

SAMPLE OF DATA.

(Wire No. 4, d=.145 mm; Load=154 g.; Approximate period=11.8 sec.)

Tape Readings	Corresponding Amplitudes	Average Time	Average Amplitude
3—32—19.85			
32—31.81			
32—43.63	254	3—32—43.62	
32—55.50			
33—07.29			
			215
3—36—39.85			
36—51.74			
37—03.47	176	3—37—03.46	
37—15.35			
37—27.00			
			149
3—41—46.30			
41—58.14			
42—09.84	122	3—42—09.87	
42—21.68			
42—33.41			

The above data were then tabulated in the following form:

Vib. No.	No. of vibs.	Ave. time (from above)	Time betw. Readings	Period (secs.)	Amp.	Ave. Amp.
		3—32—43.62			254	
11	22	3—37—03.46	259.86	11.812	176	215
35	26	3—42—09.87	306.39	11.784	122	149

The first column represents the number of vibrations that have been executed since the pendulum was set into vibration.

It might here be said that the elastic after effect was very marked in this alloy and so the zero point had to be re-determined several times during an experiment. The zero point was known to shift as far as nine degrees in the direction of the initial twist. This, of course, would introduce quite an error in the time readings if the above precautions were not taken.

THE RESULTS.

Introduction and general discussion. The experiments soon showed that there are three distinct states, from one to another of which the wires would change. The conditions under which these changes occur are very complicated but in this paper some of the conditions will be dealt with. The three period-ampli-

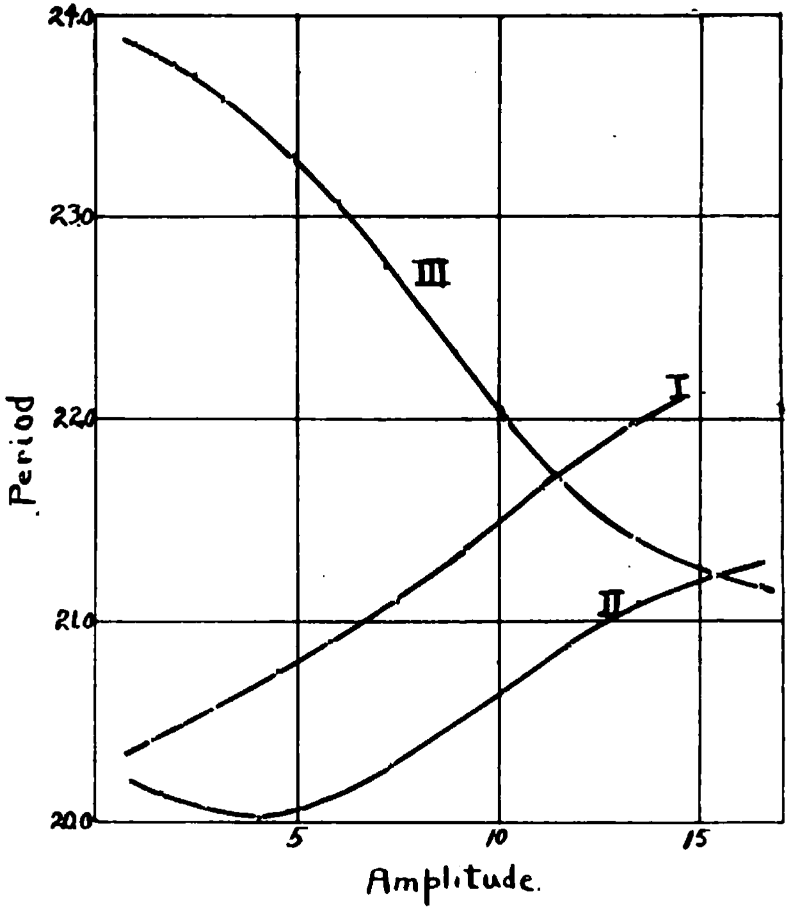

FIG. 29.

tude curves representing the three typical states are shown in figure 29. For convenience and brevity in discussion these will be numbered. They will be discussed in detail in the latter part of this paper.

Type I shall be the curve (see figure 29), in which there is a continual decrease in the period as the amplitude decreases. This departure from a constant period varies greatly in magnitude in the different wires and with the conditions imposed upon the experiment; as variations in the load and the approximate period. The same holds true also in the other types of curves. Wires when following this type of curve will be said to be in state I.

Type II is similar to the above mentioned curve in the larger amplitudes but makes a departure from that type at an amplitude of about four degrees per cm. length of the wire, and from that time on, the period gradually increases with a decrease in the amplitude. The curve is marked II (figure 29) and will represent state II.

Type III is seen to be very different from the other two. In this curve the period increases continually from the large to the small amplitudes. When the wires follow this type of curve they will be said to be in state III.

From figure 29 which shows three curves of an identical sample of wire under identical experimental conditions, it is at once seen that the variation from a constant period is very marked. The magnitude of the variation is perhaps best shown by going into these particular curves in detail.

The wire was .100 mm. in diameter (No. 1), and supported a load of 27 grams. Curve II is drawn from the data of June 6, 1915. All experiments of that time showed the wire to be in

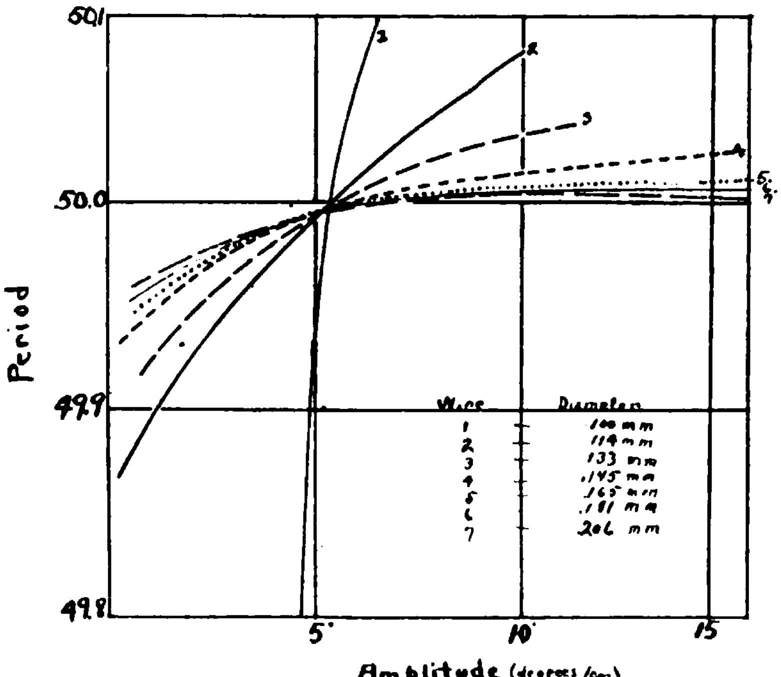

FIG. 30.

state II. The wire was then left hanging under its load through the summer months without vibration and in a room of practically constant temperature. On October 6, 1915, or four months later, the experiments were continued and the pendulum was set into vibration without any preliminary vibrations. The results of this test are shown in curve III. We see that the wire had changed from state II to state III in supporting its load during the summer.

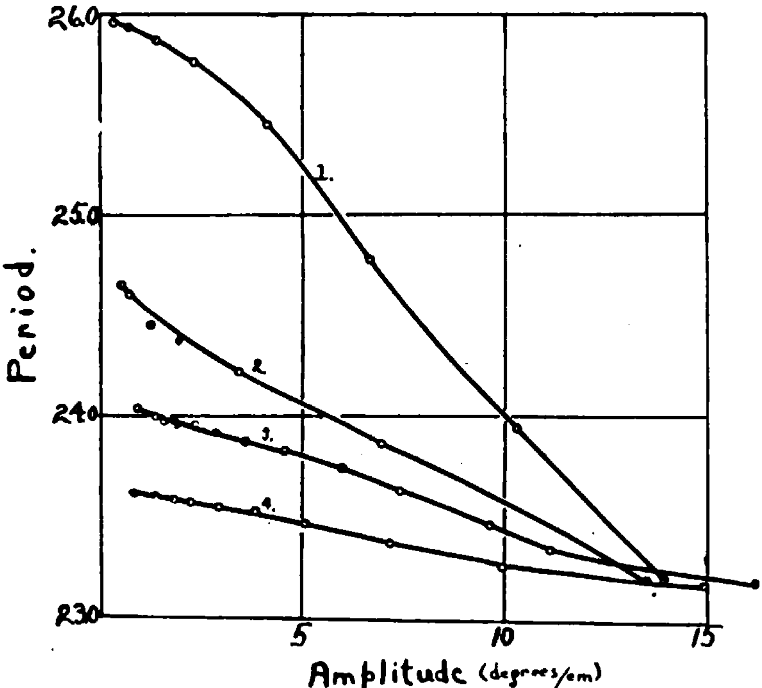

Fig 31.

From the coördinates it is readily seen that the maximum variation from a constant period, between the two curves, is about 3.85 seconds. Considering this variation with the maximum period of the two curves, it is found to be in the neighborhood of 16 per cent.

Curve I shows the identical sample of wire when in state I. It is seen that the variation from a constant period is not so marked in this type.

This phenomenon is found to be less marked as the diameter of the suspension becomes larger. In other words the drawing of the wires has a tendency to increase the effect. Figure 30 shows the results of experiments with seven successive drawings when the wires were in state I. Figure 31 shows the results of the four smallest of the above seven wires when in state III. The curves of each figure are reduced essentially, to a common period at a given amplitude. The diameter of the wires are given in figure 30. This result is similar to that found in platinum-iridium wires by Sieg[6].

[6]L. P. Sieg, Phys. Rev., Vol. 35, 1912, p. 347.

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We may here note that the wires most commonly employed for suspensions are of a diameter in the neighborhood of the smallest of these wires.

Variation of Load and Period. The existence of these three states in the wires and their causes and relations then became the object of research. If the states existed, the wires of this alloy certainly were not reliable for use in scientific instruments. The question then arose as to whether the two variables, the period of vibration and the load supported by the wires, might not be the determining factors of the resulting state.

It was soon discovered that ordinary experimentation did not alter the condition of any sample of wire and so the experiments could be repeated many times while the wire remained in essentially the same state. It was found that unless the treatments were quite strenuous, the wires always behaved essentially the same. This was verified by repeating an experiment several times in succession and the curves were always

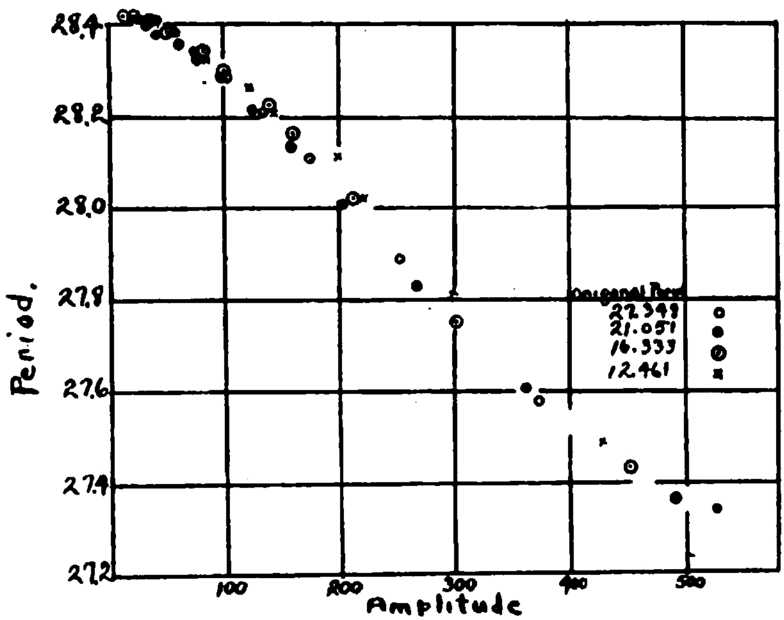

FIG. 32.

identical. In one case wire No. 3 (d=.133 mm.) was used over a period of nearly two months and the curves of this time are all of the same type.

To answer the above questions of a varying period and load, the following experiments were conducted:

Wire No. 3 was first used with four (4) widely varying periods of vibration but with a constant load and length of wire. The initial twist was the same in every case. The periods were varied by changing the moment of inertia of the pendulum.

Figure 32 shows the result of this experiment. It was immediately seen that the period-amplitude curves as well as the period-vibration number curves were similar in the four tests. Thus the period of vibration had no effect upon the state of the wire. Further than this, it was found that if each curve was multiplied by a certain factor the four curves fell practically upon a single line (see figure 32). The line has not been drawn, in order that the actual position of each curve may better be shown. The factors were simply the ratios of the periods at a certain amplitude, to any arbitrary number, and in this case they were 1, 1.3, 1.68 and 2.2. Table I below gives the original periods, the periods multiplied by the factor and the corresponding amplitudes.

TABLE I.

(1)		(2)		
K=1		K=1.3		
T.	Amp.	T.	K.xT.	Amp.
27.348	525	21.051	27.366	491
.574	373	.238	.609	360
.889	252	.414	.838	263
28.108	175	.544	28.007	205
.210	135	.644	.137	159
.292	102	.707	.219	125
.349	76	.755	.282	100
.375	58	.784	.319	79
.396	42.5	.812	.356	64
		.832	.382	52
		.823	.379	42
		.844	.297	35

(3)			(4)		
K=1.68			K=2.2		
T.	K.xT.	Amp.	T.	K.xT.	Amp.
16.333	27.439	457	12.461	27.477	428
.529	.760	301	.623	.834	296
.677	28.014	211	.744	28.101	197.6
.759	.155	160	.813	.253	119.7
.809	.239	140	.849	.332	82.7
.843	.296	104	.863	.363	63
.873	.347	81.5	.870	.378	48
			.885	.411	34
			.888	.418	22
			.891	.425	14.4
			.890	.423	9.2

Having verified this relation, the other set of conditions was then investigated. In this case there was a constant length of wire and initial amplitude but a varying load on the pendulum. At first an attempt was made to keep the periods constant in the different tests but because of the long periods of the heavy pendulums, this was found to be a slow process and in view of the previous experiment was not considered necessary. The results of this experiment are shown in figure 33.

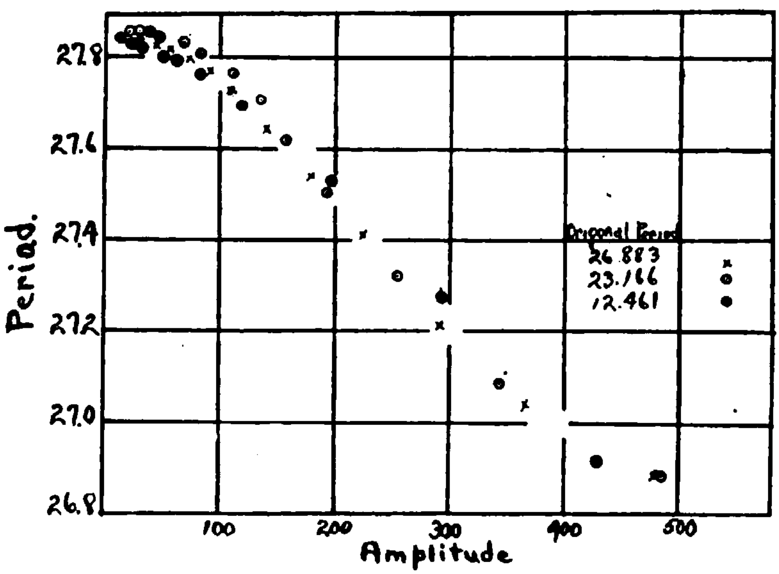

FIG. 33.

The same wire (No. 3) was used and the loads were 27, 154, and 272 grams. Again the three curves were of the same general shape and were reduced to the same period at a given amplitude. Again the factors were simply the ratios of the periods to an arbitrary number. They were in this case 1, 1.16 and 2.16. Table II below gives the data of figure 33.

TABLE II.

(1) (2)

K=1		K=1.16		
T.	Amp.	T.	K.xT.	Amp.
26.833	483	23.166	26.873	490
27.094	342	.307	27.036	366
.325	255	.465	.219	288
.502	194	.624	.404	225
.618	158	.741	.540	179
.707	138	.826	.638	139
.760	112	.886	.708	109
.803	86	.930	.759	87
.835	66	.959	.792	70
.847	46	.978	.814	58
.859	29	.995	.834	47
.859	22	24.015	.857	38
		.007	.848	28

(3)

K=2.16		
T.	K.xT.	Amp.
12.461	26.915	428
.633	27.287	296
.744	.527	197
.813	.676	119
.849	.754	82.7
.863	.784	63
.870	.799	48
.885	.832	32
.888	.838	22
.891	.845	14.4
.890	.842	9.2

The variation from a single line here is somewhat more marked than in the previous table (I) where there was a constant load. The curve (figure 33) shows, however, that the varying load has no great effect upon the period-amplitude curve. The loads were so very wide in range that it seems safe to assume that ordinary variations in the load have no effect upon the action of the wire other than changing the period of vibration.

Variation of the length of the wire with constant load.—The lengths of the supporting wires were then varied from 30 cms. to 8.9 cms. and the period-amplitude curves were plotted both for variable and constant periods (approximate periods, since the periods were never constant), at the same amplitudes per unit length. When the pendulum had the same moment of inertia for each length the periods varied as the square root of the length of the wire. This was to be expected from the formula for the period of torsional vibrations,

$$T^2 = \frac{8 \pi I L}{n r^4}$$

where I is the moment of inertia of the pendulum, L the length of the suspension, n the coefficient of simple rigidity, and r the radius of the suspension wire. The periods must of course be taken at similar amplitudes. In this experiment everything was kept constant except the period and the length, therefore we would expect to find that

$$\frac{T}{\sqrt{L}} = K$$

The four lengths 30, 23, 15 and 8.9 cms. gave the values of K as 2.43, 2.47, 2.45 and 2.45 respectively.

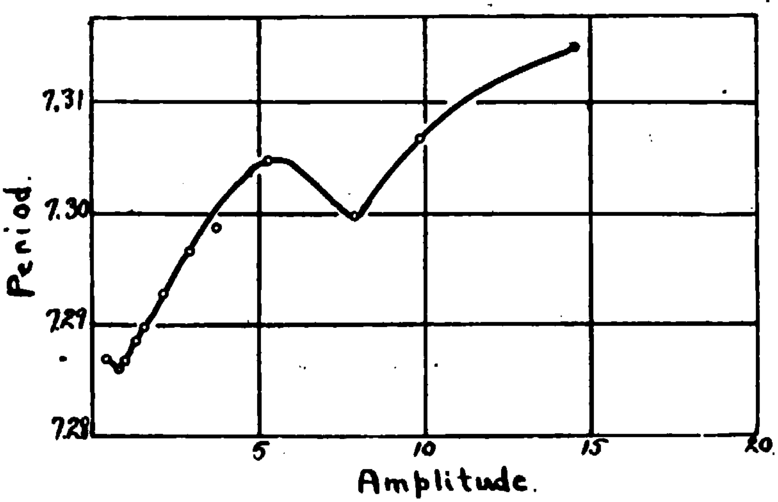

FIG. 34.

The period-amplitude curves for the shorter suspensions were somewhat unsatisfactory. The state remained the same in all cases as is shown by the general shape of the curves but the irregularities became very marked as the wire was shortened. These are not to be explained alone by the small error in the timing of the vibrations since the same tendency was noted also with the longer periods, where the error was the same as with

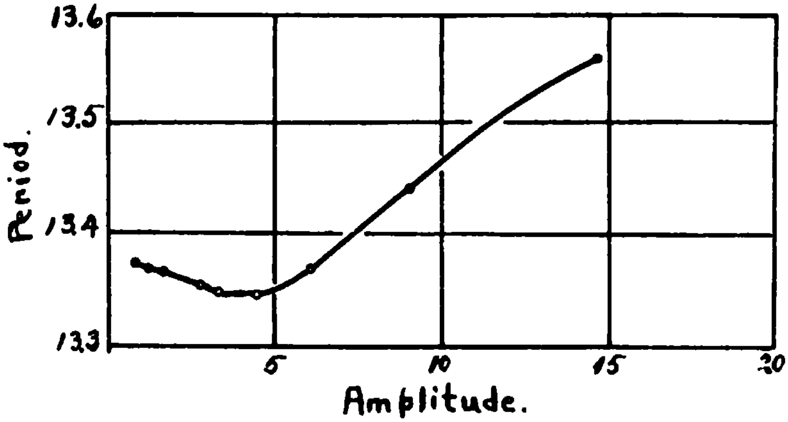

FIG. 35.

the longer suspensions. A comparison of figures 34, 35 and 36 will illustrate this point. All the curves are of wire No. 4 under a load of 154 grams. Figure 35 shows the period-amplitude curve for a 30 cm. suspension. The curve for a piece of

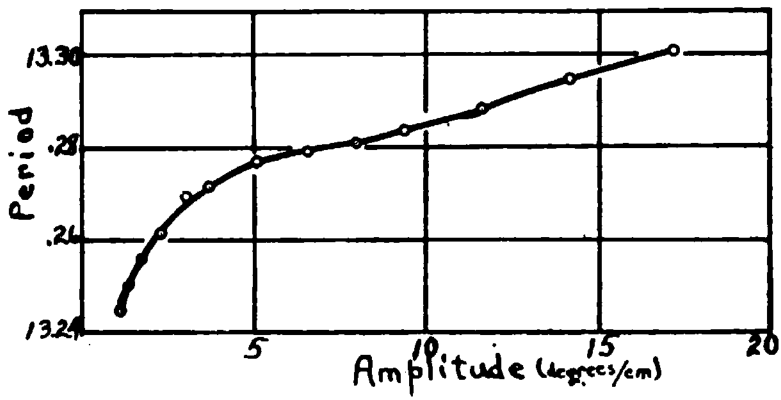

FIG. 36.

this wire, 8.9 cm. long, is shown in figure 34. Figure 36 shows the same piece vibrating with a period approximately the same as that of figure 35.

It is very probable that the shorter wires display more nearly the actual conditions in the wire whereas there may be a neutralization of some pecularities in the longer wires.

When the periods were kept constant with the above lengths the curves were somewhat more satisfactory but still had a great tendency toward irregularity. This point requires further investigation.

The most striking point to be discussed in connection with the data of these suspensions of different lengths, is that the number of vibrations required for the vibrating systems to fall between given amplitudes, increases as the wire is shortened. We can readily see that when the wire is shortest the displacement for a certain amplitude per unit length is smallest in magnitude. Since the periods were kept practically constant in these tests the angular velocity must have been greater in the longer suspensions.

Let us say that the average velocity varies as the angle of displacement and inversely as the period. Since the angle of displacement is arbitrarily taken proportional to the length, we have,

$$\bar{v}=kL/T$$

where $\bar{v}$ represents the mean velocity of the vibrating system, L the length of the wire, T the period and k a constant of the alloy.

Now assume the friction, both internal and external, to vary as the mean velocity of all the moving parts.[7] Then

$$c\bar{v} = KL/T = f$$

So, if we have variable lengths and periods we may say that if the friction is to be the same in all cases, the ratio of the lengths to the corresponding periods should be constant. (This would hold true no matter what assumptions are made in regard to the power of the velocity with which the friction varies.) Or we have

$$L/T=L'/T'$$

Now let N' be the number of vibrations between any two amplitudes per unit length and let N'' be the number for another length of the same wire between the same given amplitudes.

If N is inversely proportional to the friction,

$$N'=k/f'$$

and

$$N''=k/f''$$

or

$$N'/N''=f''/F'$$

but

$$f=KL/T$$

thus

$$N'L'/T'=N''L''/T''$$

but since the periods are kept constant $T'=T''$, and

$$N'L'=N''L''$$

or

$$N'/N''=L''/L'$$

[7]The velocity of course is a continually varying quantity but the integrated value of the velocity over a whole period varies from $\bar{v}$ by only a constant, k.

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Thus we would expect that the number of vibrations executed between any two amplitudes should vary inversely as the length, if the above assumptions are correct.

Two specimens of wire No. 4 were employed in this experiment, one showing curves of type II and the other, curves of type III. The results of the wire in state II will be discussed first. The lengths used were 30, 23, 15 and 8.9 cms. Figure 37

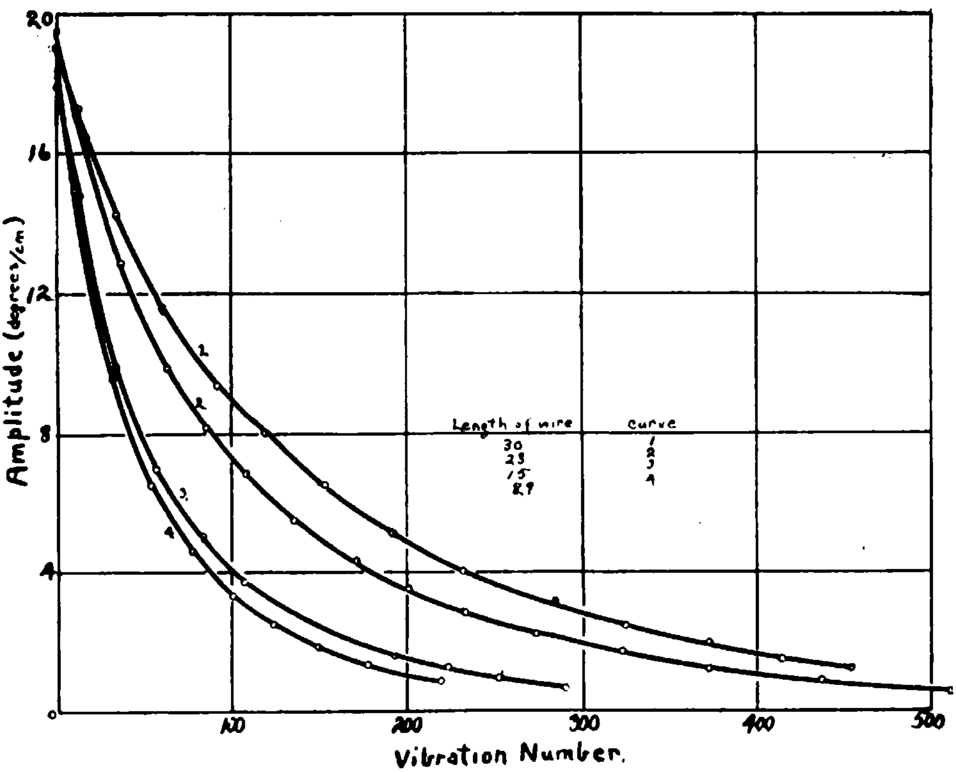

FIG. 37.

shows the vibration number-amplitude curves for the four lengths. The number of vibrations between any two common amplitudes per unit length can be interpolated from the curves.

It was found that there was essentially a constant ratio between the vibrations of any two curves, throughout the life of the vibrations. Table III gives some of the interpolated values from the four curves. The first column gives the lengths and each successive column gives the number of vibrations between the amplitudes given in the parentheses.

TABLE III.

Length	N^1 (10-3)	N^2 (10-1.5)	N^3 (18-1.5)	N^4 (14-1.5)	N^5 (18-1)
30	80(1)	140(1)	170(1)	157(1)	206(1)
23	95(1.19)	169(1.21)	201(1.18)	186(1.18)	249(1.209)
15	166(2.08)	285(2.03)	340(2.00)	318(2.03)	416(2.02)
8.9	205(2.56)	330(2.36)	406(2.39)	377(2.40)	

The ratios are given for each *N* after the number. The number of vibrations of the longest wire is arbitrarily taken as unity in each case, and the ratios for the shorter wires are figured on this basis. The mean of the four ratios for each length are 1, 1.18, 2.03 and 2.43 with mean variations of 0, .01, .03 and .07 respectively.

The values for N.L are then 30, 27, 30.4 and 21.6.

In the case of the wire in state III the lengths were 30, 22, 15 and 10 cms. The values for the above ratios of numbers of vibrations in this case were 1, 1.72, 2.36 and 3.45. The values for N.L are thus 30, 37.8, 35.4 and 34.5. We see that the product N.L is roughly constant. It must be remembered that it was impossible to make the periods exactly equal in the different lengths, since the periods would have to be made equal at equal amplitudes per unit length of the suspensions. This was practically impossible. It is also evident that if the state of the wire changes we could hardly expect a constant friction. This point will be taken up again in the discussion of the loss of energy in the two states.

It should perhaps be said that the greater per cent of all the curves were either of type II or III and hence most of the data are on these curves. State I seems to be more or less unstable and is easily changed into state II. For these reasons type I is omitted from the discussion.

Variation of the initial amplitude. In a given sample of wire, the number of vibrations required for the system to fall through a given range of degrees, varies, in a general way, inversely with the mean amplitude of this range taken. In other words the fall in amplitude is exponential. This is common to all damped vibrations.

In the phosphor-bronze wires the initial amplitude determines how rapid this fall shall be. If the initial amplitude is large the fall in the range of amplitudes common to the two experiments is more rapid than when the initial amplitude is small.

Figure 38 shows this for wire No. 4 when in state II. The initial amplitudes were 1, 4, 7 and 10 degrees per unit length respectively, for the curves 1, 2, 3 and 4. Theoretically the

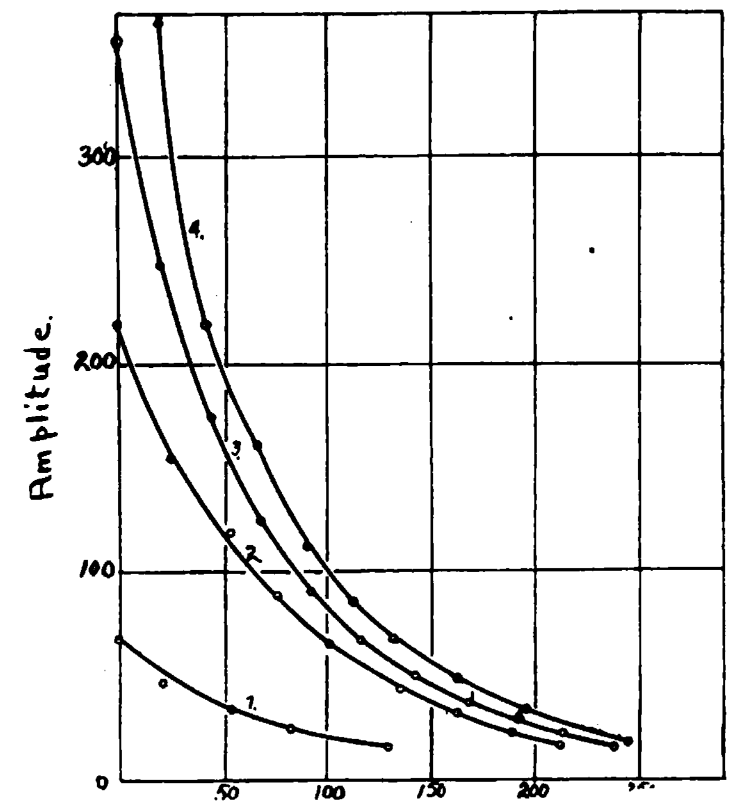

FIG. 38.

curves should be parallel but careful measurements prove that they are not. There is a progressive change in the slopes of the period-amplitude curves, the curves tending to become steeper with the larger initial amplitudes. This is not a new point but has been observed in other wires by Kelvin[8], and by Sieg[9]. We have reasons to suspect that the previous history plays a large part in this effect.

States II and III. The reasons for the peculiar conditions of phosphor-bronze wires now became the object of research. As stated above, curves II and III were the rule while those of type I were the exceptions. The very first tests showed all

[8]Kelvin, Math. and Phys. papers, p. 22.
[9]Loc. cit., p. 6.

wires from No. 1 to No. 7, inclusive, to be in state I. After that, however, this state became exceptional. To illustrate how complicated the changes of states are, the following paragraphs are given.

It has already been stated how wire No. 1 changed from state II into state III during the summer without any treatment. The wire was then vibrated artificially by means of the apparatus shown in figure 27, for 20 minutes at the rate of about 40 complete vibrations per minute. (During this process the pendulum was fixed.) The state was now I and the curve is shown in figure 29 (curve I). After another 30 minutes of rotation the wire was in state III again. Another hour of vibration had no appreciable effect.

The wire was then annealed by 1.2 amperes current in a vessel exhausted to about 3 cm. pressure and under a load of 27 grams. The first condition above was simply a precaution to prevent oxidation. The temperature became so high that the wire softened and allowed its load to fall about 1 cm. to the bottom of the annealing tube. A test now showed the wire to be in state II again. At other times the same process yielded state III.

The same inconsistencies were found in all the wires. There was never any doubt as to the state of the wires because of the magnitude of the effects.

Rates of loss of energy in states II and III. If A_1, A_2, A_3 be the successive amplitudes of vibration, we may say that

$$\text{The Potential Energy at } A_1 = \frac{\mathcal{T}_x A_1}{2}$$

where

$$\mathcal{T} = \frac{A_1 K}{L}$$

or

$$\text{P. E. at } A_1 = \frac{K A_1^2}{L}$$

and

$$\text{P. E. at } A_2 = \frac{K A_2^2}{L}$$

their difference is $\frac{K}{L}(A_1^2 - A_2^2)$

and the rate of loss of energy is $\frac{K(A_1^2 - A_2^2)}{TL}$

The rates of loss of energy were calculated for several of each type of curves. Two of each of types II and III are shown in figure 39. There is seen a tendency for type II to have a more rapid rate of loss than type III. Below an amplitude of 200 degrees (with a 30 cm. suspension), the rates of loss are essen-

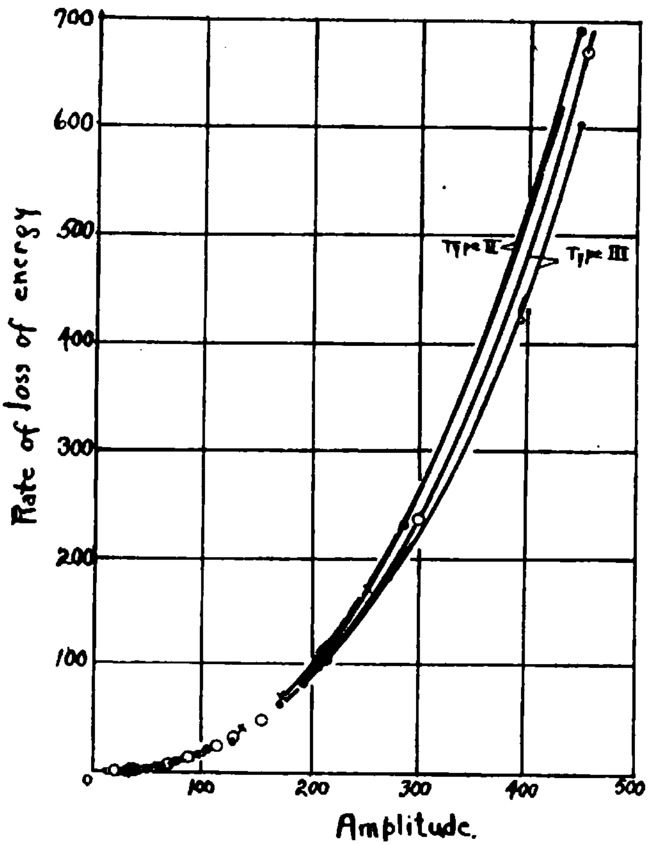

FIG. 39.

tially equal. Table IV shows the calculations for one of each type of curves. It is seen from these data that the difference between the successive angles is quite large and the calculations are thus only approximate. The data should be taken very accurately and the curves plotted on a large scale so that the rates of loss of energy may be compared. Time would not permit a more careful study of this point at this time.

TABLE IV.

Type II. Amplitude	Type II. Rate of Loss	Type III. Amplitude	Type III. Rate of Loss
413	564.1	450	650.5
255	172.4	300	239.5
177	72.2	215	107.5
128	33.8	155	45.9
96	17.3	116	25.6
74	9.3	91	14.2
57	5.5	70	8.3
44	3.1	52	4.3
34	1.8	38	2.1
25	1.3	25	.93
18	.5		

If we now assume that the rates of loss are equal in the two states, for they seem to be nearly so in the smaller amplitudes, we may say,

$$\frac{K'(A_1^2-A_2^2)}{T'L} = \frac{K'(A_1^2-A_2^2)}{LT''}$$

where T' is the steadily increasing period of type III and T'' is the decreasing period of type II. Then T' and T'' are the only variables in the above equation and if the equation is to hold

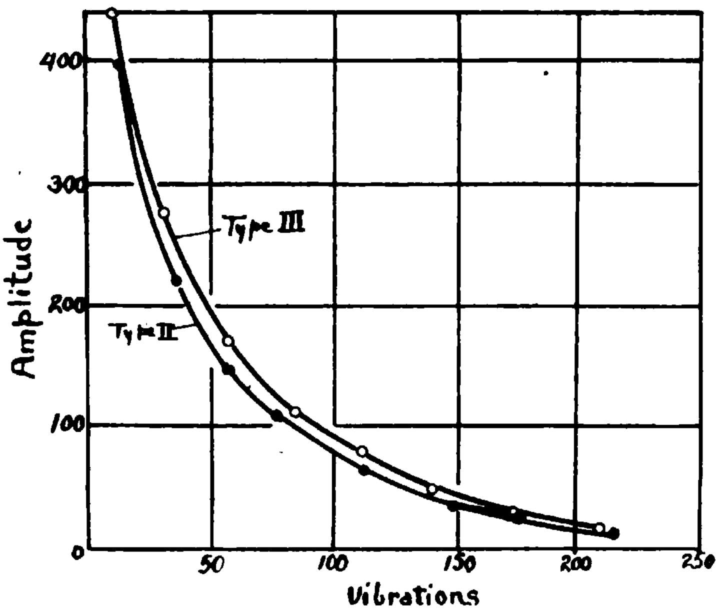

FIG. 40.

true, the value of $(A_1^2—A_2^2)$ must also increase in the left-hand side and decrease in the right-hand side of the equation. Otherwise the equality would be destroyed. Hence for equal falls in amplitude in the two types the loss of energy is smaller in the first than in the second, or we would expect to find that the amplitude-vibration number curves would be different in slope, since one would be damped more rapidly than the other. To see whether or not this reasoning was correct several curves of the two types were compared. In every case the curve of type III fell slightly above the curve of type II. This is shown in figure 40. As we should expect, the two curves tend to coincide again in the small amplitudes. This is easily explained by the fact that the period of type II again increases after the minimum at 4 degrees per cm. length. Again, as we should expect, type I continues below type III throughout the life of vibrations.

Logarithmic decrement. In ordinary damped vibrations the logarithmic decrement is constant and is expressed by log K, Where A_1, A_2, A_3, A_4,...are the successive amplitudes and bear the relation,

$$\frac{A_1}{A_2} \times \frac{A_2}{A_3} \times \frac{A_3}{A_4} \times \frac{A_{n-1}}{A_n} = K^{n-1}$$

$$\frac{A_1}{A^n} = K^{n-1}$$

$$\text{then} \qquad \log K = \frac{\log A_1 - \log A_n}{n\text{-}1}$$

Table V below shows how the log K varies in a sample of wire No. 4. These tables have been compiled for several curves of each type for several diameters of wires and all are found to be very irregular with a general tendency for the log K to fall off in the smaller amplitudes. Thus nothing of value can be learned from the log K curves of the different states. The log K has no real meaning in these cases.

TABLE V.

Wire No. 4 in state II. (Length=8.9 cms.)

Mean Amplitude	Log K
130.5	.0056
88	.0046
65	.0032
47	.0040
34	.0033
26	.0039
20	.0036
14	.0025
11	.0036

The effecting of states II and III. The inconsistencies of the effect of annealing and vibrating the wires were at first difficult to explain. The conditions were evidently very complicated. In annealing, even when the variables of the process, the load, the current and the time of annealing were kept constant, there was no regularity in the results. A very high temperature by a large current would cause one state at one time and another state at another time. The wires were heated to a dull red glow and still the state could not be predicted. Wires Nos. 3 and 4 were then annealed by different currents, to determine whether there were not perhaps definite lower temperatures at which definite states would result. The currents were varied by .1 ampere between the range of .2 ampere up to 1.8 amperes when the wires began to glow. After each annealing, the previous history of the wire was destroyed by the largest current the wire would carry. Still there was no regularity of results.

The slow or sudden cooling of the wires after annealing, gave no clue. At first the time of annealing seemed to have no effect upon the resulting state. Long continued vibrating by the motor usually changed the state but unless the process was long continued nothing could be predicted. It was, however, noted that when the time of artificial vibration was very long state II would usually result. Only one exception to this has been found and that was a sample of wire No. 3, which was not changed from state III in 13.5 hours of continued vibration. The required time to bring about state II was found to be in the neighborhood of 12 hours for wire No. 4. In general the required time is shorter for the smaller wires and longer for the larger wires.

The most recent work has shown that long annealing by a comparatively large current, with the wire supporting a small load, gives state III. Wire No. 4 was annealed by 1.0 ampere while it supported a load of about 25 grams, and in four different trials has always been changed to state III. The same wire under a load of 154 grams was not changed from state II by the same current in 38 hours. This point requires some further investigation before a definite relation of temperature and the resulting state of the wire can be stated. In general, we may say that long annealing with the wire under a small load, and at a comparatively high temperature, causes state III. On the other hand long continued vibration causes state II.

SUMMARY AND CONCLUSION.

The main points of this paper on the elastic properties of phosphor-bronze wire, are:

1. There are three states in which the wires appear.
2. Drawing of the wires has a tendency to increase the effect of a varying period with the amplitude.
3. The magnitude of the period of vibration and the load supported by the wire have no appreciable effect upon the period-amplitude curves.
4. In a given sample of wire with a constant load and period, the number of vibrations executed during a fall of a given number of degrees in amplitude, varies inversely as the length of the suspension. $N x L = K$.
5. The initial amplitude determines to a certain extent the rate of loss of energy of the pendulum.
6. In the larger amplitudes state II has a more rapid rate of loss of energy than state III and their rates tend to become equal in the smaller amplitudes.
7. The amplitude-vibration number curve of state III is gentler in slope than the one of state II but the two coincide in the smaller amplitudes.
8. In general, long continued annealing at a comparatively high temperature brings about state III.
9. Long continued vibration will, in general, bring about state II.

In conclusion we must say that phosphor-bronze wires are certainly not fit for use in delicate suspensions. The elastic peculiarities are too complicated to be corrected for.

While these elastic properties may be typical of this alloy alone, it is reasonable to suspect that other alloys have their distinct peculiarities just as platinum-iridium and these wires were found to have.

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