May 16, 1895.

The LORD KELVIN, D.C.L., LL.D., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On Measurements of small Strains in the Testing of Materials and Structures." By J. A. EWING, M.A., F.R.S., Professor of Mechanism and Applied Mechanics in the University of Cambridge. Received April 24, 1895.

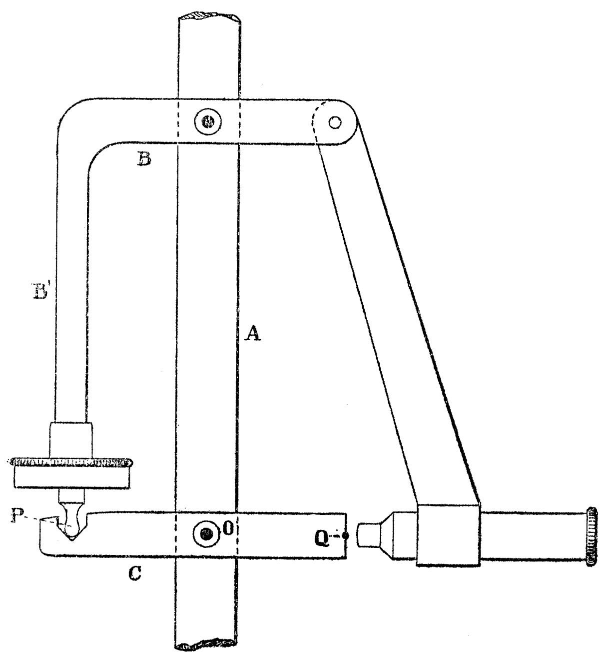
Many forms of "extensometer" have been devised for measuring the small strains of extension or compression which precede yielding in materials subjected to stress by direct pull or push. Such instruments are employed, in the testing of metals, for determining Young's modulus and for observing the behaviour of the material as the limit of elasticity is passed. Apparatus of the same general kind has also been applied to examine the strains produced in the members of bridges and other structures by the application of load to the structure as a whole; the amount of stress in any member being in that case inferred from observation of the strain. Professor Unwin, who has himself designed more than one form of extensometer, has described in his work on the 'Testing of Materials of Construction' a number of instruments of this class, and has pointed out that a first condition of accuracy is that the measurements of extension be made on both of two sides of the piece, in such a way that a mean is obtained representing the extension of a central line. In practice, a rod always bends more or less on being pulled. Even when the rod is initially straight the pull is rarely, if ever, so symmetrically applied or the elasticity so uniform as to make the extension equal at all parts of the section. Hence, to avoid errors which would be great relative to the quantity under examination, the extensometer must be arranged in such a fashion that its indications depend only on the change of distance between two points on the axis of the rod, and are independent of those inequalities which are found to exist in the strains as measured on the surface. The condition is met either by taking two separate observations of the strain on two sides of the rod and averaging the two, or by making

the extensometer itself indicate a mean strain. Bauschinger's apparatus, in which two mirrors are used to indicate separately the strains on opposite sides of the rod, is an example of the first method. Professor Unwin's extensometer, in which the rod is grasped by a pair of clips at the extremities of two parallel diameters, the change of distance between the clips being measured, in an example of the other.

The object of the present paper is to describe an instrument of the same class, but embodying some novel features, and to mention a few results that have been obtained by its means.

The instrument is self-contained, is entirely supported by the rod under test, and touches the rod only at the points where the clips are attached—a feature which is of advantage in view of the tendency the rod has to bend. The principle of the construction will be seen on referring to the diagrammatic sketch, fig. 1. To the rod A, which is

FIG. 1.



the piece under test, the two pieces B and C are attached each by a pair of set screws. Each of these pieces has, separately, one degree of freedom with respect to the rod, namely, freedom to rotate about the axis of its set screws. Hence, B has two degrees of freedom rela-

tively to C, so long as the two are not otherwise connected. But the piece B has fixed to it an arm B′, which ends in a rounded point P, and this point gears in a V-slot cut transversely across the end of the piece C. The contact of P with the two sides of this slot removes the two degrees of freedom which B would otherwise have relatively to C, and makes the position of the pieces definite. Then, when the rod extends, the point P acts as a fulcrum, and the opposite end of C, namely, Q, moves down through a distance proportional to the mean displacement of the two pairs of set screws. The displacement of Q is a multiple of the strain, in the ratio of PQ to OQ. This displacement is measured by means of a microscope, which hangs from B and sights an object at Q. The strains to be observed are so small that it is easy, without making the piece C inconveniently long, to prevent its angular movement from becoming sufficient to prove troublesome or to affect the accuracy of the indications. The arm B′, which carries the point P, must be so attached to B that, as regards oscillation about the set-screws of B, the two pieces B and B′ move as a rigid whole. But B′ may be flexible in the direction which would give P motion at right angles to the plane of the paper, and by giving it flexibility of this kind (while preserving its rigidity as regards motion in the plane of the paper) the point P may be made to gear in a hole instead of a slot in C. There is a practical advantage in doing this, for if P gears in a slot any unequal extension of the front and back of the specimen makes P work along the slot, and it is difficult to secure that no error will result in consequence of the slot not being perfectly parallel to the axes of the set-screws. This consideration has led the author to adopt the plan of putting a transverse joint between the pieces B and B′, with the object of giving P freedom to adjust itself to a hole (instead of a slot) in C, by movement about this joint in a direction perpendicular to the plane of the sketch. Incidently, such a joint has the further advantage that it allows the whole apparatus to be more conveniently and quickly applied to the rod under examination.

The displacement of Q due to the strain is measured by means of a micrometer in the eye-piece of the microscope. A micrometer scale engraved on glass is convenient for the purpose, and by estimating tenths of a division on such a scale readings are readily taken which correspond to $\frac{1}{50000}$ of an inch of extension on the part of the specimen, with an objective which allows the whole of the elastic extension to occur without displacing Q beyond the field of view.

There is a fine screw with a divided head between B′ and the point P. This serves to bring Q into a convenient position for sighting, and also to determine what is the absolute amount of extension corresponding to a division of the eye-piece scale. Should a strain occur

exceeding the range of the eye-piece scale, Q is brought back into the field of view by turning P through a distance which is observed by means of a divided head.

FIG. 2.

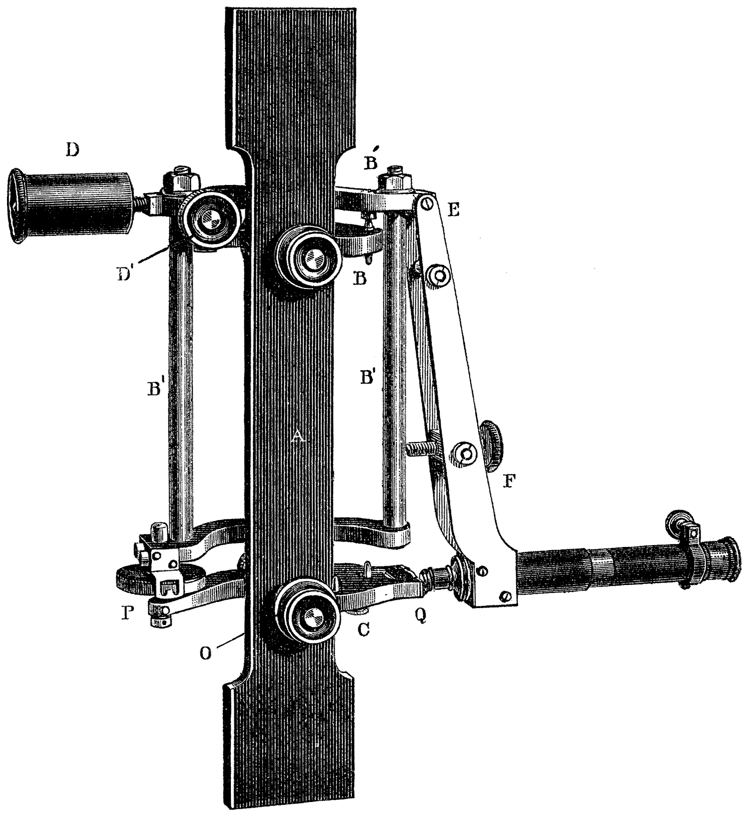


Fig. 2 is a view of the complete instrument, taken from a photograph. The clips B and C are in this instance set at 8 inches apart, and B is jointed to B′ by a transverse joint, giving P freedom to accommodate itself to a hole in C. The joint between B and B consists of two upright pins fixed in B, one of which presses up into a hole and the other into a slot in B′, the line of this hole and slot being perpendicular to the axis of the set-screws by which the clip is attached to the rod under test. Hence, so far as movement about the axis of the set-screws is concerned, B and B′ act as a rigid whole. This movement is prevented by the gearing of P in the hole in the lower clip C. The piece B′ is a frame consisting of two

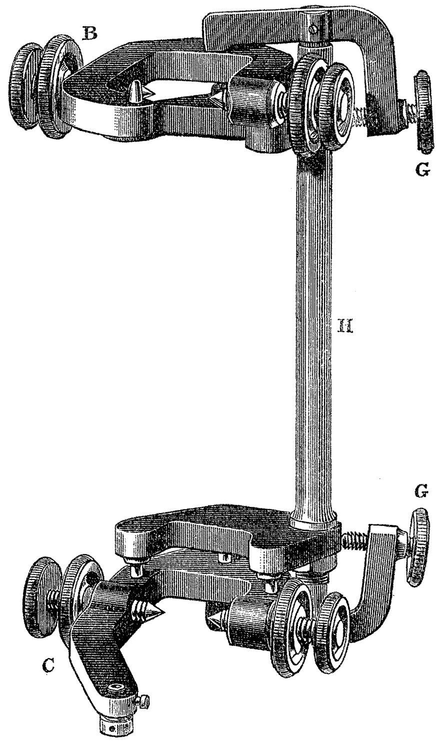
parallel steel rods united by a cross-bar at top and bottom, and carrying, besides the screw P, the microscope, which is hinged to B′ about the point E vertically above Q, and is provided with a focussing screw at F. The counterpoise D, which is also attached to the piece B′, serves to balance the weight of the microscope and make the pressure vertical between P and the hole into which it gears. There is a supplementary counterpoise D′ for adjusting the balance about the axis of the joint between B and B′. These counterpoises are adjusted until when the heavy end (Q) of C is raised, so that P ceases to be in gear with C, P has no tendency to move in any direction. The excess of weight on the right hand side of C suffices to produce the requisite pressure at the point P. The frame BB′ with the microscope may be lifted off, leaving only the two clips attached to the rod.

The object sighted is one side of a wire stretched horizontally across a hole in a plate at Q, and illuminated by a small mirror behind. The distances OP and OQ are in this instance equal, with the effect that the movement of Q is double the extension of the rod. The eye-piece scale and the length of the microscope are chosen so that the numbers read on the scale correspond to $\frac{1}{50000}$ of an inch of extension. This adjustment is tested by turning the screw P, which has a pitch of $\frac{1}{50}$ inch, through one revolution, and observing that the displacement of Q is 500 units of the eye-piece scale. In the instrument illustrated in fig. 2 the whole scale comprises 1,400 units, and calibration tests show that throughout the middle 1,200 of them the proportionality of the scale readings with the real movements of Q is practically perfect.

To facilitate the application of the apparatus to any rod a clamp or distance piece, H (fig. 3), is added by which the two clips, B and C, may be held at the right distance apart, and with the axes of their set screws parallel. This makes it in many cases unnecessary to prepare the rod beforehand by punching or drilling holes for points of the set screws; the clamp is readily held so that the clips stand fairly round the rod; the set screws are advanced to grip the rod, and the clamp is then removed by releasing the screws, GG. The connection of the clamp to each of the clips is by means of three points gearing with a hole, slot, and plane. The clamp is specially convenient when the strain of the specimen has been carried beyond the elastic limit, and it is desired immediately to reset the clips to the standard distance apart after the length between them has been materially changed by the permanent extension of the specimen.

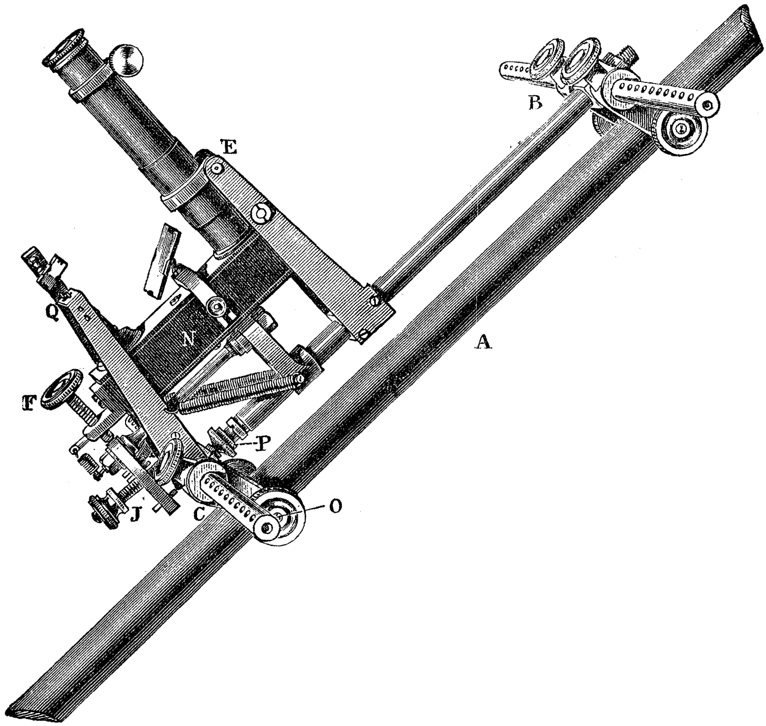
Another form of the apparatus designed for use on the members of actual structures, is shown in fig. 4. There are essentially the same parts, but the arrangement is altered in order to make all the apparatus lie on one side of the piece under examination—a desirable and

Fig. 3.



often necessary condition in the application of the instrument to such pieces as the girder flanges. The clips are (as in Professor Unwin's extensometer) adjustable to wide or narrow bars. The pieces B and C engage by means of a screw-point in a hole, the necessary pressure being supplied by springs, with the effect that the apparatus can be used in any position, horizontal, vertical, or inclined (as in the figure). The sighted wire Q, is on a prolongation of C beyond P, giving a mechanical multiplication of three to one. Between the objective and the eye-piece of the microscope is the box N, containing a series of two totally reflecting prisms, which turn the line of sight through two right angles. This arrangement keeps all parts of the instrument compactly together on one side of the bar or plate under test. A clamp is provided at J which, by the tightening up of a single nut, disengages P from its hole and fixes the two portions, B and C, in relation to one another, so that the instrument may then be handled as a rigid whole, and be readily applied to the bar which is to be tested, the axes of the clips being then parallel and at the proper distance

FIG. 4.



apart. When the instrument has been put in place, and the clip screws tightened up, the nut J is released, P comes into gear, and things are ready for the observation to be taken.

The following are examples of tests made with the author's extensometer in its laboratory form. The pieces were loaded, in tension, by means of the 50-ton Wicksteed single-lever testing machine of the Cambridge Engineering Laboratory. The machine is worked by a hydraulic intensifier, which affords a particularly convenient means of varying the load gradually without shock and without setting the weigh-beam into oscillation. Except when otherwise stated, the increments of load were made at intervals of about one minute, that interval sufficing for the adjustment of the load to a new value, and for reading the extensometer. The unit of the extensometer scale readings is in all cases $\frac{1}{50000}$ inch.

(1.) Turned bar of mild steel. Diameter, 1·249 inches. Length under measurement, 8 inches. Temperature, 57° F. Zero of extensometer set at 400. Results of three successive loadings within the elastic limit :—

Load in tons.	Extensometer readings.			Differences.		
	First loading.	Second loading.	Third loading.	First loading.	Second loading.	Third loading.
0	400	400	400			
$2\frac{1}{2}$	461	461	461	61	61	61
5	522	522	522	61	61	61
$7\frac{1}{2}$	583	583	583	61	61	61
10	645	645	645	62	62	62
$12\frac{1}{2}$	707	706	707	62	61	62
15	769	768	768	62	62	61
$17\frac{1}{2}$	830	829	830	61	61	62
20	892	891	891	62	62	61
0	400	400	400	492	491	491

Each ton corresponds in this case to a stress of 0·817 ton per square inch. Taking the whole extension due to 20 tons to be 491, or 0·00982 inch, Young's modulus is

$$E = \frac{8 \times 20 \times 0{\cdot}817}{0{\cdot}00982} = 13310 \text{ tons per sq. inch.}$$

(2.) Turned bar of tool steel. Diameter, 0·706 inch. Length under measurement, 9 inches. Temperature, 57° F. The bar had not been previously loaded beyond 6 tons.

Load in tons.	Extensometer readings.	Differences. Per ton.	Differences. Per half-ton.
0	100	—	—
1	184	84	—
2	268	84	—
3	352	84	—
4	437	85	—
5	522	85	—
6	606	85	—
$6\frac{1}{2}$	649	—	43
7	691	85	42
$7\frac{1}{2}$	733	—	42
8	776	85	43
$8\frac{1}{2}$	819	—	43
9	862	86	43
$9\frac{1}{2}$	904	—	42
10	947	85	43
$10\frac{1}{2}$	990	—	43
11	1032	85	42
$11\frac{1}{2}$	1075	—	43

	Load in tons.	Extensometer readings.	Differences. Per ton.	Per half-ton.
	12	1119	87	44
Unload	0	100½	—	—
Reload	12	1119	—	—
	12½	1163	—	44
	13	1206	87	43
	13½	1249	—	43
	14	1292	86	43

The load was then removed, observation being taken at these stages :—

Load.	Extensometer.
10	950
7	693
5	523
0	101½

Here each ton of load corresponds to 2·56 tons per square inch. The mean extension up to 10 tons is 84·7 per ton, and corresponds to a Young's modulus, E, of 13600 tons per square inch. The extension per ton increases slightly, but perceptibly, with the later loads, although the almost complete absence of set after 12 tons, and even after 14, shows that there was no very clear passing of an elastic limit, even under the greatest strain of 35·8 tons per square inch. There is just a trace of hysteresis in the relation of strain to stress which shows itself in the removal of the load.

These two examples, relating as they do to cases where Hooke's law of the proportionality of strain to stress is very approximately true, may be taken to serve as tests of the sensibility and accuracy of the extensometer.

In the examples which follow, the limits were passed within which Hooke's law applies. In augmenting the stress so as to pass these limits, it very generally happens that one of the first evidences of overstrain is a time effect—a creeping up of the extensometer reading—while the load is kept constant for a few minutes. This creeping, which is a familiar phenomenon in the measurement of strains, can usually be detected a good way before the yield point is reached. It is associated with failure in proportionality of strain to stress, and also with permanent, or semi-permanent set. In certain conditions of the material as regards previous treatment, this creeping is far more marked than in other conditions. It shows itself most when the piece has, immediately before the test, been subjected to a load sufficient to cause permanent yielding to occur. But if the same piece is allowed to rest for some days, and is then re-tested, the tendency to creeping is found to have disappeared or to be much

reduced in consequence of the hardening and recovery of elasticity which the overstrained material undergoes with the mere lapse of time.

The following observations were made with a turned rod of common wrought iron, the original diameter of which was 0·697 inch (section 0·381 square inch). Length under measurement, 9 inches. Each ton of load corresponds to 2·65 tons per square inch. The rod was annealed after being turned. The first loading, after annealing, gave the following results:—

(3A.) Common Iron, annealed.

	Load in tons.	Extensometer readings.	Differences. Per half-ton.	Differences. Per ton.	
	0	200	—	—	
	½	250	50	—	
	1	299	49	—	
	1½	447	48	—	
	2	395	48	—	
	2½	441	46	—	
	3	488	47	—	
	3½	536	48	—	
	4	582	46	—	
Unload	0	201	—	—	(Set = 1)
Reload	1	300	—	—	
	2	395	—	95	
	3	490	—	95	
	4	584	—	94	
	4½	631	47	—	
	5	682	51	—	
Unload	0	208	—	—	(Set = 8)
Reload	5	682	—	—	
	5·2	702	Creeping to 703 in 1 minute.		
	5·4	721	Creeping to 724 in 1 minute.		
	5·6	749	Creeping to 750 in 10 seconds.		
	5·8	773	Creeping to 774 in 10 seconds.		
	6·0	810	Creeping to 820 in 1 minute.		

With this load of 6 tons the yield point was reached. The creeping under the load was at first slow, then gradually became accelerated, and, finally, the sighted wire of the extensometer ran quickly off the scale. At the same time the oxide formed in annealing began to come off in the way characteristic of the yield point. The scaling of the oxide began at one place in the bar and spread gradually in both directions. The load of 6 tons was kept on without altera-

tion for about three minutes while this was happening, and when it was removed there was a permanent extension of 0·10 inch on the marked length of 9 inches.

The extensometer was immediately reset to the normal length of 9 inches, an operation which occupied two or three minutes more, after which the bar was reloaded as follows :—

(3B.) Same piece after stretching by a load of 6 tons.

	Load in tons.	Extensometer.		Difference per ton.
	0	200		—
	1	297		97
	2	395		98
	3	497		102
	4	600	(Creeping)	
		601	After 1 minute.	104
Unload	0	202	(Creeping back)	
		200	After 1 minute.	
Reload	1	297		97
	2	395		98
	3	495		100
	4	598		103
	5	705		—
		707	After 20 seconds.	109
	$5\frac{1}{2}$	767		—
		770	After 20 seconds.	
Unload	0	214		—
		210	After 3 minutes.	
		208	After 45 minutes.	

These figures show how widely different are the elastic qualities of an iron bar in its primitive annealed condition, and in the condition in which it is put by overstrain. In the first condition there is almost no evidence of creeping or " elastische nachwirkung " up to say 5 tons of load, and Hooke's law is nearly valid. Immediately after an overstrain there are distinct evidences of creeping at lower loads, and when these lower loads are removed, there is the same kind of thing in the unloaded state, namely, an apparent set which disappears in whole or in part when time is allowed for the creeping to take effect. And further, after the overstrain there is no longer nearly so close an agreement with Hooke's law; a given increment of load produces notably more strain at high loads than at low ones. In loading and unloading there is now much hysteresis in the relation of strain to stress.

In the overstrained state the lowest loads produce not much more strain than they did in the primitive state; the value of Young's

modulus so far as very small strains are concerned is scarcely changed. But if the modulus be calculated by reference to the effects of higher loads, it will be much smaller in the overstrained bar. This has been noticed by Bauschinger, who has also observed the tendency, illustrated in tests to be described below, which iron and steel show to recover their elasticity with the lapse of time, after overstrain has taken place.*

On resuming the above experiment, 45 minutes after the previous load had been removed, the influence of the overstrain was still conspicuous.

Load in tons.	Extensometer.		Difference per ton.
0	208		—
1	304		96
2	402		98
3	501		99
4	602		101
5	708		(106)
	710	After 20 seconds.	108
6	833		—
	850	After 1 minute.	
0	244		—
	240	After 1 minute.	

The bar was then taken out of the testing machine and left to itself for 5 days. On the fifth day the following readings were taken; they show in a striking way the effect of this interval of rest:—

(3c.) Same piece after resting for 5 days.

Load in tons.	Extensometer.	Difference per ton.
0	200	—
1	296	96
2	392	96
3	490	98
4	588	98
5	685	97
6	782	97
0	200	—
6	782	—
0	200	—

* See also a paper by the present writer ("On certain Effects of Stress," 'Roy. Soc. Proc.,' No. 205, 1880), which gives instances of the rise of the yield-point with lapse of time, a phenomenon evidently having a close relation to the rise of the modulus.

The tendency to creep has now practically disappeared so far as this range of load is concerned; the strain is very nearly proportional to the stress, and there is no set. It will be remembered that 6 tons was the greatest load formerly applied, and that it brought the piece to the yield-point in the original test.

The loading was then resumed, and was carried a stage further to see how far the new yield-point would be above the old one.

Load in tons.	Extensometer.	Difference per ton.
0	200	—
1	296	96
2	393	97
3	490	97
4	588	98
5	685	97
6	782	97
$6\frac{1}{2}$	832	—
7	908	Creeping, at first slow, then faster, and tending to run off the scale.
0	600	Showing 400 divisions, or 0·008 inch, of further permanent extension.

The zero of the extensometer was now brought back to 200, and the loading was immediately repeated, to see whether this small amount of further overstrain had undone, to any extent, the molecular settlement which had been going on during the 5 days of rest.

Load in tons.	Extensometer.	Difference per ton.
0	200	—
1	297	97
2	395	98
3	492	97
4	591	99
5	692	101
6	793	101
0	204	Creeping back to 202, but not further.

It is clear from these figures that the elasticity has again been, to some extent, injured by the overstrain at the 7-ton load, small as that was; and one effect is that even a load of 6 tons now produces some persistent set.

The following are values of Young's modulus E, for this bar, calculated from the foregoing experiments (3A, 3B, and 3C).

Primitive Annealed State (3A).

Mean extension from 1 to 4 tons = 94·5 per ton ;
E = 12500 tons per square inch.

Immediately after passing yield-point (3B), the diameter was reduced by the set to 0·693 inch, and the section to 0·377 square inch.

Extension for first ton = 97 ; E = 12310.
Mean extension from 0 to 2 tons = 97·5 ; E = 12250.
Mean extension from 0 to 4 tons = 100·2 ; E = 11910.
Mean extension from 0 to 5 tons = 101·4 ; E = 11770.

After elastic recovery by resting for 5 days (3C).

Mean extension from 0 to 6 tons = 97 ; E = 12310.

After a small amount of further overstrain (by applying 7 tons).

Extension for first ton = 97 ; E = 12310.
Mean extension from 0 to 6 tons = 99 ; E = 12060.

Similar results have been obtained in tests of other bars, of mild steel, comparatively hard steel, and Lowmoor iron. In every case, overstrain has produced a like fatigue of elasticity, and elastic recovery has followed during an interval of some days or weeks of rest.

In several examples the process of passing the yield-point has been watched in the extensometer and has been seen to take place in the same manner as in test (3A). Creeping, which has been slightly visible under lower loads, takes place at first slowly, then it gradually gets faster, though no change is made in the load. This may go on for a minute or two before the crepitation of oxide begins. The following is an instance noticed in testing a bar of mild steel. The load having been increased a step, and kept constant, there were

3	scale-divisions of creep	in the	first	minute
9	„	„	second	„
320	„	„	third	„

after which the index of the extensometer raced off the scale. In another case the writer noticed creeping going on quite slowly, when a sound of crepitation was heard. On looking at the bar it was seen that the crepitation had begun near one end, beyond the clips. As soon as it spread far enough to reach the clip there was, of course, a rapid movement of the index.

The following test will suffice in further illustration of the

influence of overstrain and subsequent rest. It was made on a turned bar of moderately hard, or semi-mild steel, which had not been previously loaded beyond 6 tons. The diameter was 0·705 inch, and the section 0·390 sq. inch. The length under test was 9 inches.

(4A.) Semi-mild Steel. Primitive state.

Load in tons.	Extensometer.	Differences. Per ton.	Differences. Per half-ton.
0	200	—	—
1	287	87	—
2	373	86	—
3	459	86	—
4	544	85	—
5	630	86	—
0	200	—	—
5	630	—	—
5½	672	—	42
6	715	—	43
6½	758	—	43
7	800	—	42
7½	843	—	43
8	885	—	42
8½	929	—	44
9	970	—	41
9½	1010	—	40
10	1053	—	43
0	201	—	—
10	1054	—	—
10½	1099	—	45
11	Yield-point passed; permanent extension produced = 0·14 inch on the 9-inch length.		

The load was removed and the extensometer reset to 9 inches, and the following test was immediately made, beginning 10 minutes after the yielding took place:—

(4B.) Same piece, after stretching by a load of 11 tons.

Load in tons.	Extensometer.	Difference per half-ton.
0	200	—
½	243	43
1	287	44
1½	331	44

Load in tons.	Extensometer.		Difference per half ton.
2	377		46
$2\frac{1}{2}$	422		45
3	469		47
$3\frac{1}{2}$	517		48
4	565		48
$4\frac{1}{2}$	613		48
5	662		49
0	200		48
5	661		—
$5\frac{1}{2}$	710		49
6	760		50
$6\frac{1}{2}$	812		52
7	866		54
$7\frac{1}{2}$	920		54
8	975		—
	977	After 30 seconds.	
0	208		—
	203	After 2 minutes.	
8	974		—
	977	After 1 minute.	
0	210		—
	207	After 30 seconds.	
	202	After 3 minutes.	
	200	After 20 minutes.	

As in the example already given, the influence of overstrain is apparent (1) by the presence of creeping or "nachwirkung," and (2) by the progressive growth of the differences as the load increases. The first ton or so produces little more strain than it did before the overstrain took place, but the eighth ton produces a quarter as much again.

An hour after the yielding had taken place the load was again reapplied in stages of 1 ton as follows, and the extensometer readings already show something of elastic recovery through rest. They are given in the following table, along with readings taken on the following day and on subsequent days. It is interesting to notice the rather slow progress of the elastic recovery from day to day. It takes place much less rapidly in this comparatively hard metal than in milder steel or in wrought iron. To facilitate comparison the readings taken immediately after the overstrain are repeated here:—

Successive Loadings of the same Piece, after various Intervals of Time.

Load in tons.	(4B.) Ten minutes after overstrain.		(4C.) One hour after overstrain.		(4D.) One day after overstrain.		(4E.) Two days after overstrain.		(4F.) Three days after overstrain.		(4G.) Five days after overstrain.		(4H.) Twenty-one days after overstrain.	
	Extensometer readings.	Differences.	Extensometer readings.	Differences.	Extensometer readings.	Differences.	Extensometer readings.	Differences.	Extensometer readings.	Differences.	Extensometer readings.	Differences.	Extensometer readings.	Differences.
0	200	—	200	—	200	—	200	—	200	—	200	—	200	—
1	287	87	287	87	286	86	286	86	286	86	286	86	285	85
2	377	90	376	89	373	87	372	86	372	86	372	86	371	86
3	469	92	467	91	463	90	461	89	461	89	460	88	458	87
4	565	96	562	95	559	96	556	95	553	92	550	90	545	87
5	662	97	660	98	658	99	653	97	650	97	643	93	632	87
6	760	98	760	100	758	100	754	101	750	100	741	98	720	88
7	866	106	862	102	860	102	857	103	853	103	844	103	810	90
8	976	110	969	107	963	103	960	103	958	105	950	106	900	90
0	208 to 203	—	206 to 200	—	203 to 200	—	203 to 200	—	203 to 200	—	203 to 200	—	$200\frac{1}{2}$ to 200	—

These figures show that even after three weeks the elastic recovery is still somewhat incomplete. This is the more remarkable when it is borne in mind that the testing is done here with a load of 8 tons only, a considerably smaller load than that which had been applied to produce permanent set (namely 11 tons). The imperfection which the elasticity still shows after three weeks of rest would be more conspicuous if the loading were extended beyond 8 tons.

Throughout this group of tests evidences were seen of much elastic "nachwirkung." If a load exceeding, say, 4 tons, was left on for a few minutes there was continued extension, amounting sometimes to as much as five scale divisions. And when the load of 8 tons was removed there was, as the table indicates, a gradual retraction which in a few minutes destroyed the apparent set observable at the moment of removing the load. In the final observation (4H) this action had almost wholly disappeared, but even then a trace of it could be detected.

As elastic recovery goes on in the days or weeks following overstrain there is a gradual return towards Hooke's law, or as it might be described in other terms, a gradual straightening out of the stress-strain curve. So long as the recovery is incomplete there can scarcely be said to be any elastic limit, in the sense of a point below which there is strict proportionality of strain to stress.

For the Young's modulus of this bar the tests give the following values:—

(4A.) Primitive condition (before overstrain).
Section 0·390 square inch.

Mean extension from 0 to 8 tons = 85·6 divisions per ton.
E = 13480 tons per square inch.

(4B.) Immediately after stretching past the yield-point by 11 tons. Section 0·385 square inch.

Extension for the first ton = 87; E = 13440.
Mean extension from 0 to 8 tons = 97 per ton; E = 12060.

(4G.) After 5 days' rest.

Extension for the first 2 tons = 86 per ton; E = 13600.
Mean extension from 0 to 8 tons = 93·7 per ton; E = 12480.

(4H.) After 21 days' rest.

Extension for the first 2 tons = 85·5 per ton; E = 13670.
Mean extension from 0 to 8 tons = 87·5 per ton; E = 13370.

The behaviour of iron or steel when "fatigued" by overstrain, and before recovery of elasticity has taken place through prolonged rest,

much resembles that of a brass rod in its normal state. The following is a test of a turned rod of rolled brass with a section of 0·386 square inch. The length under measurement was 9 inches.

Load.	Extensometer.	Difference per half-ton.
0	200	—
$\frac{1}{2}$	281	81
1	362	81
$1\frac{1}{2}$	443	81
2	525	82
$2\frac{1}{2}$	607	82
3	690	83
$3\frac{1}{2}$	772	82
4	856	84
$4\frac{1}{2}$	941	85
0	200	—
$4\frac{1}{2}$	942	—
5	1031	89
0	202	—
5	1036 to 1037	—
$5\frac{1}{2}$	1129 to 1130	93
0	212 to 210	—

Under the higher loads there was a distinct creeping, with a corresponding creeping back after the load was removed.

Taking 163 divisions per ton as the extension under small loads, the value of E is 7160 tons per square inch.

The last test to be cited is that of a "steel" casting of the specially pure kind now extensively used to form the cores of dynamo magnets. The rod was turned from a steel casting by the makers (Messrs. Edgar Allen and Co.), and had been submitted to the writer for a magnetic test, which had shown it to have exceptionally high permeability under strong magnetic forces. It consisted of nearly pure iron. The diameter was 0·753 inch.

Load.	Extensometer.	Difference per half-ton.	Set.
0	200	—	—
$\frac{1}{2}$	237	37	—
1	273	36	—
$1\frac{1}{2}$	310	37	—
2	347	37	—
$2\frac{1}{2}$	384	37	—
3	423	39	—
0	204	—	4 (apparently persistent).

Load.	Extensometer.	Difference per half-ton.	Set.
3	424	—	—
$3\frac{1}{2}$	468 to 470	44 to 46	—
4	528 to 540	58 to 70	—
0	249	—	49
4	545 to 550	—	—
$4\frac{1}{2}$	670	—	—
	715 after half a minute.		
	758 after two minutes.		
	785 after nine minutes.		
0	447	—	247
$4\frac{1}{2}$	798	—	—
5	1200 running slowly off the scale.		

The mean extension from 0 to $2\frac{1}{2}$ tons is 73·6 per ton, which makes E = 13740 tons per square inch.

II. "The Electrical Measurement of Starlight. Observations made at the Observatory of Daramona House, co. Westmeath, in April, 1895. Preliminary Report." By G. M. MINCHIN, M.A. Communicated by Professor FITZGERALD, F.R.S. Received April 29, 1895.

The method employed in these experiments for measuring the intensity of the light which reaches the earth from the stars and planets consists in the determination of the electromotive force generated by such light in certain photo-electric cells, the square of this electromotive force being proportional to the energy of the incident light.

It will, then, be well to describe first the nature and construction of these cells.

The Photo-electric Cells.

In these cells the surface on which the incident light is received is formed by depositing a thin layer of selenium on a surface of clean aluminium, and immersing the sensitive layer in a glass cell filled with œnanthol.

The mode of formation of the sensitive surface is as follows:—

FIG. 1.

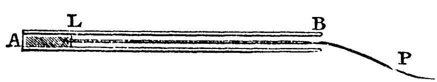


FIG. 2.

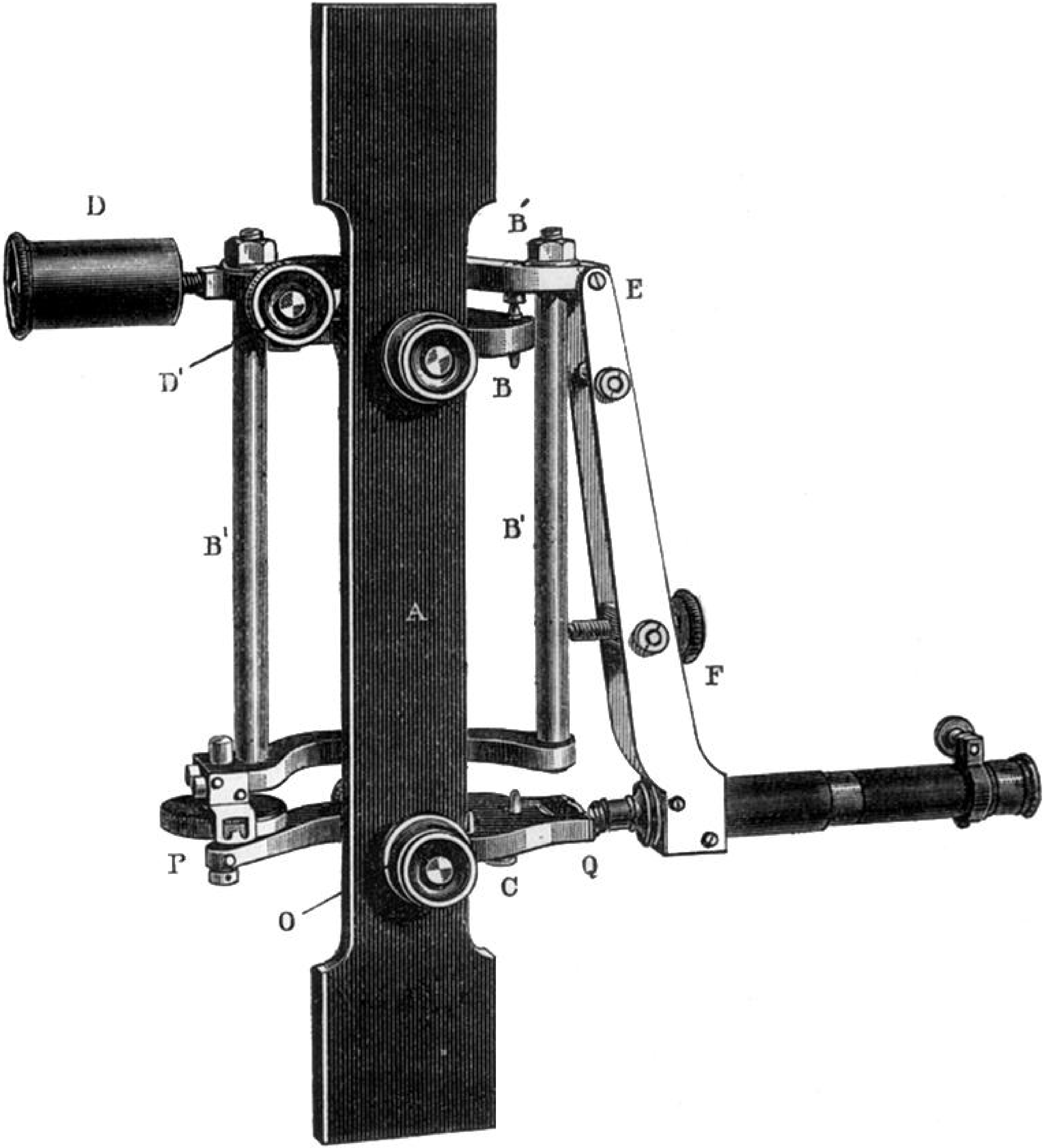


FIG. 3.

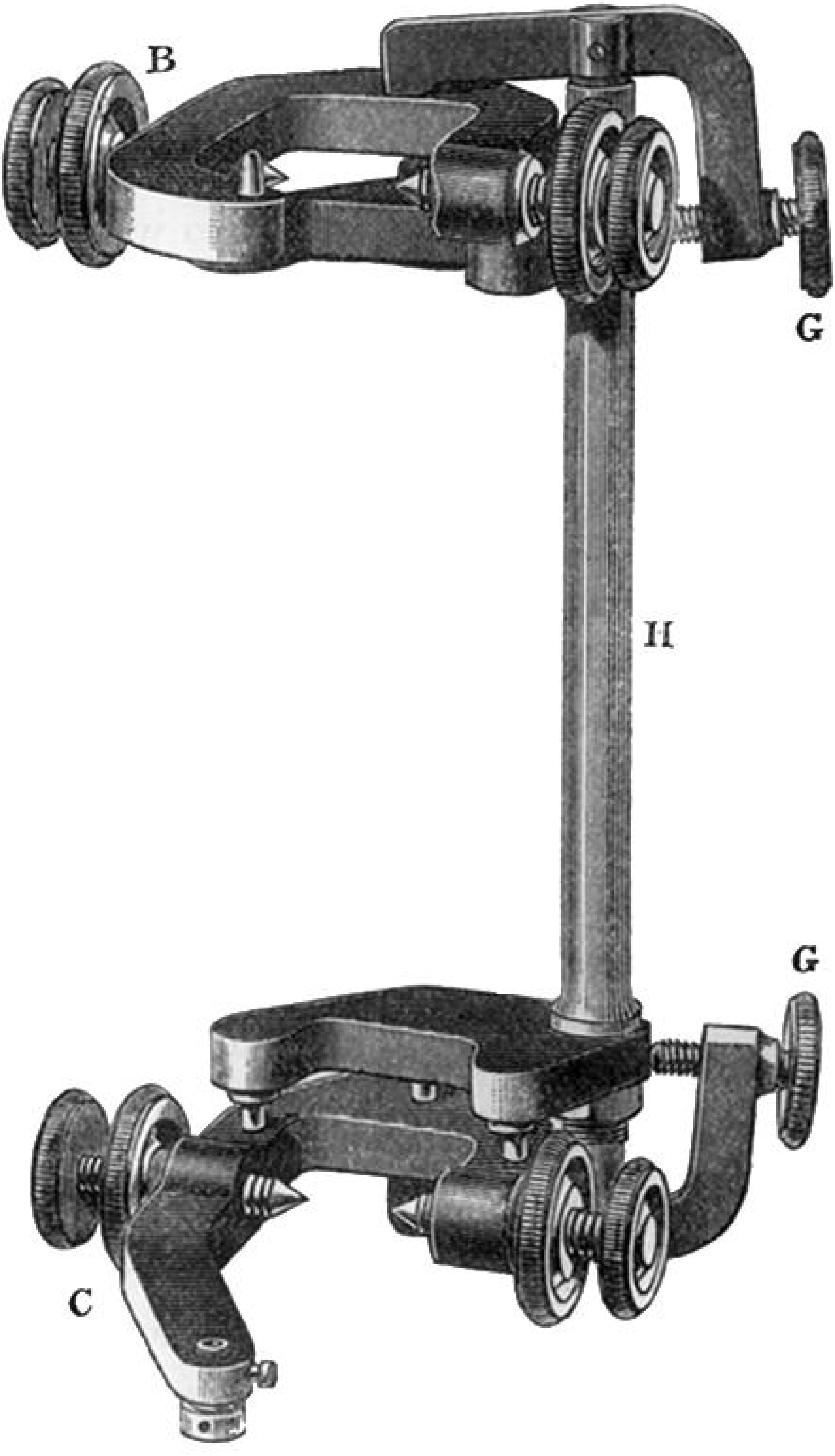


FIG. 4.