was prevented from buckling by being supported in a trough with partitions. The full line gives the strain produced by loading; it is continuous through the origin, showing that Young’s modulus is the same for pull and push. (Similar experiments on wrought iron and steel in extension and compression have given the same result.) The broken line shows the set produced by each load. Hodgkinson found that some set could be de­tected after even the smallest loads had been applied. This is probably due to the existence of initial internal stress in the metal, produced by unequally rapid cooling in different por­tions of the cast bar. A second loading of the same piece showed a much closer approach to perfect elasticity. The elastic limit is, at the best, ill defined; but by the time the ultimate load is reached the set has become a more considerable part of the whole strain. The pull curves in the diagram ex­tend to the point of rupture; the compression curves are drawn only up to a stage at which the bar buckled (between the partitions) so much as to affect the results.

*Autographic Recorders.—*Testing machines are sometimes fitted with autographic appliances for drawing strain diagrams. When the load is measured by a weight travelling on a steelyard, the diagram may be drawn by connecting the weight with a drum by means of a wire or cord, so that the drum is made to revolve through angles proportional to the travel of the weight. At the same time another wire, fastened to a clip near one end of the specimen, and passing over a pulley near the other end, draws a pencil through distances proportional to the strain, and so traces a diagram of stress and strain on a sheet of paper stretched round the drum.@@1 In Wicksteed’s autographic recorder the stress is determined by reference, not to the load on the lever, but to the pres­sure in the hydraulic cylinder by which stress is applied. The main cylinder is in communication with a small auxiliary hydraulic cylinder, the plunger of which is kept rotating to avoid friction at its packing. This plunger abuts against a spring, so that the distance through which it is pushed out varies with the pressure in the main cylinder. A drum covered with paper moves with the plunger under a fixed pencil, and is also caused to rotate by a wire from the specimen through distances proportional to the strain. The scale of loads is calibrated by occasional reference to the weighted lever.@@2 In Kennedy’s apparatus autographic diagrams are drawn by applying the stress to the test-piece through an elastic master-bar of larger section. The master-bar is never strained beyond its elastic limit, and within that limit its extension furnishes an accurage measure of the stress; this gives motion to a pencil, which writes on a paper moved by the extension of the test-piece.@@3 In R. H. Thurston’s pendulum machine for torsion tests, a cam attached to the pendulum moves a pencil through distances proportional to the stress, while a paper drum attached to the other end of the test-piece turns under the pencil through distances proportional to the angle of twist.@@4

*Strain beyond the Elastic Limit: Influence of Time.—*In testing a plastic material such as wrought-iron or mild steel it is found that the behaviour of the metal depends very materially on the time rate at which stress is applied. When once the elastic limit is passed the full strain corresponding to a given load is reached only after a perceptible time, sometimes even a long

time. If the load be increased to a value exceeding the elastic limit, and then kept constant, the metal will be seen to draw out (if the stress be one of pull), at first rapidly and then more slowly. When the applied load is considerably less than the ultimate strength of the piece (as tested in the ordinary way by steady increment of load) it appears that this process of slow extension comes at last to an end. On the other hand, when the applied load is nearly equal to the ultimate strength, the flow of the metal continues until rupture occurs. Then, as in the former case, extension goes on at first quickly, then slowly, but finally, instead of approaching an asymptotic limit, it quickens again as the piece approaches rupture. The same phenomena are observed in the bending of timber and other materials when in the form of beams. If, instead of being subjected to a constant load, a test-piece is set in a constant condition of strain, it is found that the stress required to maintain this constant strain gradually decreases.

The gradual flow which goes on under constant stress— approaching a limit if the stress is moderate in amount, and continuing without limit if the stress is sufficiently great—will still go on at a diminished rate if the amount of stress be reduced. Thus, in the testing of soft iron or mild steel by a machine in which the stress is applied by hydraulic power, a stage is reached soon after the limit of elasticity is passed at which the metal begins to flow with great rapidity. The pumps often do not keep pace with this, and the result is that, if the lever is to be kept floating, the weight on it must be run back. Under this reduced stress the flow continues, more slowly than be­fore, until presently the pumps recover their lost ground and the increase of stress is resumed. Again, near the point of rupture, the flow again becomes specially rapid ; the weight on the lever has again to be run back, and the specimen finally breaks under a diminished load. These features are well shown by fig. 12, which is copied from the autographic diagram of a test of mild steel.

*Hardening Effect of Permanent Set.—*But it is not only through what we may call the viscosity of materials that the time rate of loading affects their behaviour under test. In iron and steel, and probably in some other metals, time has another effect of a very remarkable kind. Let the test be carried to any point *a* (fig. 13) past the original limit of elasticity. Let the load then be removed; during the first stages of this removal the material continues to stretch slightly, as has been explained above. Let the load then be at once replaced and loading continued. It will then be found that there is a new yield-point *b* at or near the value of the load formerly reached. The full line *be* in fig. 13 shows the subsequent behaviour of the piece. But now let the experiment be repeated on another sample, with this difference, that an interval of time, of a few hours or more, is allowed to elapse after the load is removed and before it is replaced. It will then be found that a process of hardening has been going on during this interval of rest; for when the loading is continued the new yield-point appears, not at *b* as formerly, but at a higher load *d.* Other evidence that a change has taken place is afforded by the fact that the ultimate extension is reduced and the ultimate strength is increased (e, fig. 13).

A similar and even more marked hardening occurs when a load (exceeding the original elastic limit), instead of being removed and replaced, is kept on for a sufficient length of time without change. When loading is resumed a new yield-point

@@@1 For descriptions of these and other types of autographic recorder, see a paper by Professor W. C. Unwin, “On the Employment of Autographic Records in Testing Materials,” *Journ. Soc. Arts* (Feb., 1886) ; also Sir A. B. W. Kennedy’s paper, “ On the Use and Equip­ment of Engineering Laboratories,’1 *Proc. Inst. Civ. Eng.* (1886), which contains much valuable information on the whole subject of testing and testing machines. On the general subject of tests see also Adolf Martens’s *Handbook of Testing Materials,* trans, by G. C. Henning.

*@@@2 Proc. Inst. Meeh. Eng.* (1886). An interesting feature of this apparatus is a device for preventing error in the diagram through motion of the test-piece as a whole.

*@@@\* Proc. Inst. Meeh. Eng.* (1886); also *Proc. Inst. Civ. Eng.* vol. lxxxviii. pl. I (1886).

@@@4 Thurston’s *Materials of Engineering,* pt. ii. For accounts of work done with this machine, see *Trans. Amer. Soc. Civ. Eng.* (from 1876); also, *Report* of the American Board, cited above.