transit. The line joining these points is the graph required, hour angle for any position being read off at foot of chart, and zenith distance on margin.

Here polar distance $(p) = 90°$, co-latitude $(c) = (90° - 60°) = 30°$.

Therefore $(p-c)$ for left margin $= 90° - 30° = 60°$.
,, $(p+c)$,, right ,, $= 90° + 30° = 120°$.

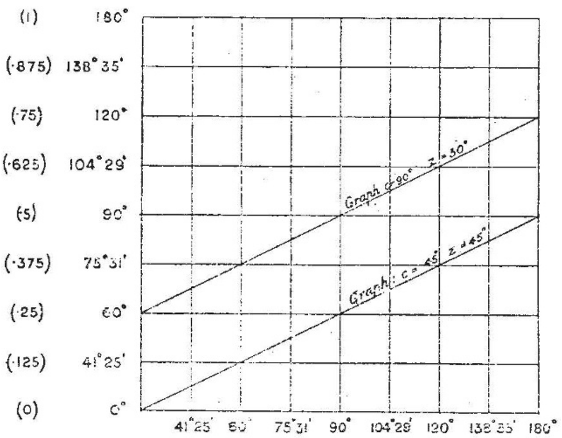
The graph being drawn accordingly, at 4h., or 60°, read off at foot of chart, we have zenith distance 73° 31′ on margin. When the sun is setting the zenith distance is 90°, and the hour angle is also 90°, or 6 hours. To find the hour angle at the end of twilight—that is, when the sun has a depression of 18°—we have to draw the parallel for 90° + 18°, or 108°. The graph intersects this in the point (*a*), which would be found on measurement to correspond approximately with 8h. 33m. P.M.

Azimuth and Polar Distance.

Interchanging polar distance (*p*) and zenith distance (*z*), the procedure will be very much as before.

Example 2.—At a place on the equator find the azimuth of bodies of declination 14° 29′ N., 0°, 14° 29′ S., the altitude in each case being 60°.

Rule.—On left-hand margin mark $(z \sim c)$, and on right-hand margin $(z+c)$. Join these points, and azimuth for any position is read off on base, and polar distance on margin.



Here $(c-z) = 90° - 30° = 60°$, $(c+z) = 90° + 30° = 120°$. For declination 14° 29′ N., we have polar distance 75° 31′, and azimuth N. 60° W.; for declination 0°, polar distance is 90°, and azimuth N. 90° W.; for declination 14° 29′ S., polar distance is 104° 29′, and azimuth N. 120° W. or S. 60° W.

The following is an example of the converse case in which declination is obtained from azimuth:—In latitude 45° N. find the declination of a body which passes the prime vertical at an altitude equal to the latitude of place. For $(z-c)$ we have the value zero, so that the graph passes through the origin, while $(z+c) = 90°$. If the bearing is 90°, we have polar distance 60°, so that declination is 30° N. If the azimuth is 60°, it is also evident from the diagram that polar distance is 41° 25′, and declination 48° 35′ N.

The deduction of declination from observed altitude and approximate azimuth is of value at sea to identify an unknown star.

The most obvious use of the diagram is to supply an exceedingly simple graphic method for azimuth. In theory the diagram can be used with equal facility for hour angle. But in the latter problem much greater accuracy is required than in the other, and the diagram necessary would have to be upon too large a scale to be available for ordinary use at sea. It is quite possible, however, that another kind of navigation may become a matter of daily experience ere long, viz. the long-distance navigation of the air, and that in this form of navigation, which will undoubtedly possess many features peculiar to itself, the diagram may serve generally not only for azimuth purposes, but also for those of hour angle.

In the words of the inventor of the diagram:—"The feasibility thus disclosed of framing a nautical astronomy in which all requirements will be subserved by a single trigonometrical table, like the table of haversines, No. 45 in the *American Practical Navigator*, invested the subject with interest from the point of view of aerial navigation, because this formula, if successfully represented in graphical form, might provide the aerial navigator with the equivalent of a volume on nautical astronomy in a form simple enough to fulfil the instant needs of flight."

H. B. G.

EXPERIMENTAL STUDIES OF THE MECHANICAL PROPERTIES OF MATERIALS.[1]

THE general purpose of experiment on materials is to distinguish between the fit and unfit, the suitable and unsuitable materials for the various requirements of the structural and mechanical work of the world. The special object of the engineer in testing materials is to obtain a rational basis for proportioning structures and machines so that they may sustain the straining actions to which they are subjected without fracture or prejudicial deformation, and at the same time without waste of material. Nor is there any finality in such testing, for new alloys, new heat treatments, new conditions of use are always making fresh investigation necessary. In the next place, the mechanical properties of materials desired and assumed in designing are embodied in specifications. Thence arises a second occasion for experiment. Tests of reception or inspection tests are necessary to determine whether material supplied reaches the required standard. With the widening of the sources of supply, an engineer can no longer depend merely on the reputation of the seller, but must make his own tests.

Early Researches.

There are two methods, said Roger Bacon in the thirteenth century, by which we acquire knowledge—argument and experiment; and he proved the fertility of the method of experiment in contrast with the barren dialectics of his time. But it was some centuries later before anything was done to ascertain by experiment the data required by the engineer in using materials of construction. Yet there is no subject of greater importance to engineers, or of more intellectual interest, than the study of the mechanical properties of materials which fit them for use in construction. Nor is there one which more deeply concerns the general public who depend on the product of machinery and travel on railways.

The earliest known experiments on the strength of materials were made by Galileo[2] in 1638, and not long after Muschenbroek,[3] of Leyden, made many tests on a small scale, some of which are quoted in Barlow's "Strength of Materials." Galileo knew nothing of elasticity, but he determined the tenacity of copper and started an inquiry into the strength of beams, giving a solution partly right, partly wrong.

[1] From the Thomas Hawksley Lecture delivered before the Institution of Mechanical Engineers on October 4 by Dr. W. Cawthorne Unwin, F.R.S.

[2] Fontenelle, "Histoire de l'Académie des Sciences," 1702.

[3] "Introductio ad cohærentiam corporum firmorum," 1729; Barlow, "Strength of Materials," 1867, p. 3.

A step of the highest importance practically and theoretically was the publication in 1678, by Robert Hooke, "an Englishman of great genius but unpleasant temperament," of the empirical law that stress is proportional to strain.[4] Then in 1680 Mariotte, who independently discovered Hooke's law, indicated that the resistance of a beam is due to tension on one part and thrust on the other part of a section. Coulomb,[5] later, more scientifically obtained the equation of equilibrium by resolving horizontally the forces at a cross-section and equating the moment to that of the external forces on either side of the section.

In 1807 Thomas Young[6] defined the coefficient of elasticity or Young's modulus—an epoch-making advance because of the clearness it introduced into elastic reasoning. Arthur Schuster says that Young was probably, next to Leonardo da Vinci, the most versatile genius in history, and Helmholtz said that he was one of the most clear-sighted men that ever lived.

Early Practical Testing.

In the latter half of the eighteenth century a group of distinguished engineers and architects concerned in constructing a bridge over the Seine and the Pantheon or Church of St. Geneviève at Paris, finding the need for information, built testing machines of 20 to 100 tons capacity. Among them were Perronet,[7] Rondelet,[8] Gauthey,[9] and Girard.[10]

In 1817 Peter Barlow published an essay on the strength of timber and other materials founded on tests made at Woolwich. In 1825 Navier,[11] charged with the construction of a suspension bridge at Paris, required all the members to be subjected to a proof load of 10 tons per sq. in., and about 4000 pieces were tested with loads up to 70 tons. Navier had also made a great advance in theory in first investigating the general equations of equilibrium of an elastic solid.

It will be already clear that knowledge of materials was progressing along two independent lines—that of experiment and that of analysis. In the latter half of the eighteenth century mathematicians of the highest rank were applying themselves to the problems presented by the resistance and deformation of solid bodies. But mathematics is a kind of mill the product of which depends on the data with which it is fed. While experimental data were wanting, there were errors and misunderstandings in the theoretical investigation of elasticity. Prof. Love[12] says that in 1820 "the fruit of all the ingenuity expended by mathematicians on elastic problems might be summed up as—an inadequate theory of flexure, an erroneous theory of torsion, an improved theory of the vibrations of bars, and the definition of Young's modulus." But practical engineers had at this time accumulated considerable empirical knowledge of the resistance of materials. No one can overrate the importance to the engineer of theoretical researches in applied mechanics, but that branch of science is outside the purpose of this lecture.

Considerable advances in knowledge of strength of materials were made by Eaton Hodgkinson, who, though largely self-taught, had considerable mathematical ability and skill in observation. The precise position of the neutral axis of the cross-section of a beam seems to have been first demonstrated in a paper on transverse strain and strength of materials in 1822.[13] Between 1847 and 1853 he was professor of engineering at University College, London. In 1830[14] he carried out the well-known experiments on the most economical form of cast-iron beams, and in 1840 and 1857[15] he published researches on the strength of columns which form the basis of practical rules still in use. Though Hodgkinson's apparatus was rough, he so designed his tests that the results were accurate to a small limit of error.

The Conway and Menai Bridges.[16]

A great advance arose out of the circumstances attending the construction of the Menai and Conway tubular bridges. A railway had to be carried over spans not before accomplished for such work. Robert Stephenson imagined a suspension bridge with platform stiffened by wrought-iron girders, and there still exist in the piers of the Menai Bridge arrangements for supporting chains. Early, however, Sir William Fairbairn, from experience with ships, formed the opinion that girders would support themselves without chains. Much knowledge was found to be wanting, and very extensive experiments on a large scale were carried out in 1845–48, in which Fairbairn, Hodgkinson, and Edwin Clark assisted, and many scientific authorities were consulted. There was a great clearing-up of ideas as to the laws of transverse strength, especially in the case of built-up structures, and as to provision against buckling of members in compression—a fundamental question, as we have learned in the case of the Quebec Bridge.

The most novel expedient was the testing of a model of the Menai Bridge, one-sixth of full size. The model was of 75-ft. span and 4½ ft. deep. It was broken six times by dead weight, being repaired where weakest after each fracture. In this way its strength was increased from 35·5 to 86·1 tons, or, including its own weight, from 38 to 89 tons. Hence was deduced a law for geometrically similar tubes, namely that the strength increased only as the square of the linear dimensions, but the weight as the cube. It follows that there is a limit of increase of dimensions for a girder of any given type and material at which the stresses due to the weight of the structure become equal to the safe working stress on the material—a limit approached in some modern bridges.

The Britannia and Conway bridges were successfully completed, and gave rise to the types of girder bridges which have prevailed from that time. But it is interesting that Eaton Hodgkinson almost to the last considered that suspension chains would be necessary, and Edwin Clark states that with few exceptions scientific men either remained neutral or ominously shook their heads and hoped for the best.[17]

Effect of the Introduction of Steel.

Wrought-iron was a material of tolerably uniform quality, but steel varies in its properties through a wide range, and in the early days was sometimes treacherous. Hence came about the demand for much more general and systematic testing. In 1858 Messrs. Robert Napier and Sons proposed to use steel in some high-pressure boilers. Doubtful as to the quality of the so-called homogeneous metal and puddled steel then manufactured, they employed Mr. David Kirkaldy to make tests which, it is believed under the advice of

4 "De potentia restitutiva." (London, 1678.)
5 "Essai sur une application des règles de maximis et minimis," Mém. par divers savans, 1776.
6 "Lectures on Natural Philosophy and the Mechanical Arts." Lecture III., 1807.
7 Lesage, "2nd Recueil de Mémoires des Ponts et Chaussées," 1808, p. 151.
8 "Traité de l'art de bâtir," 6th ed., 1830.
9 "Œuvres de Gauthey," 1909, p. 269; *Journal de Physique*, de l'Abbé Rozier, 1774, p. 402.
10 "Traité analytique de la résistance des solides," 1798.
11 "Notice sur le pont des Invalides," p. 284.
12 "Treatise on the Theory of Elasticity," 1892, p. 5.
13 Memoirs of Manchester Philosophical Society, vol. iv.
14 *Ibid.*, vol. v.
15 Phil. Trans.
16 "Britannia and Conway Bridges," Edwin Clark, 1850.
17 *Loc. cit.*, vol. i., p. 298.

Rankine, covered a wide range. The results were published in 1862.[18] The testing machine was a single-lever machine, with no adequate means of taking up the strain during loading. The investigation led to the construction by Mr. Kirkaldy in London of a large machine of about 400 tons capacity, and the establishment of the first testing laboratory where tests were carried out for anyone requiring them. No doubt Mr. Kirkaldy's research had much to do with the adoption of the tensile test as the usual test of reception for iron and steel. From general considerations it might be argued that a torsion test or a shear test would have answered equally well.

Combined Stresses.

A branch of the subject on which our experimental knowledge is still imperfect is the resistance to combined stresses; for instance, the case of combined bending and torsion, or combined hoop and longitudinal stress. The most important investigation is that of Guest in 1900,[19] in which the yield-point was determined in cases of thin tubes subjected to combinations of tension, torsion, and internal fluid pressure. The result has been the general adoption in calculating crank-shafts of the theoretical formula for the equivalent bending moment M , due to a bending moment M and twisting moment T,.

$$M_e = \sqrt{(M^2 + T^2)},$$

which is usually termed Guest's law. No tests of varying or alternating combined stresses have been made, and there is here an important field for future research.

In this review of experimental work it is not possible to pass over the researches of a remarkable man, Johann Bauschinger (1832–93), the son of an artisan at Nuremberg, thrown on his own resources at the age of fourteen. Taught in the technical school, he became professor of physics and mathematics at Augsburg and Fürth, and afterwards of mechanics at Munich. He made one of the earliest researches on locomotives, in which indicator diagrams were taken when running. He established the first public laboratory, supported by Government, for testing materials, and introduced methods of accuracy not previously attempted, measuring extensions, for instance, to 1/250,000 of an inch. He first indicated the similarity of deformation in geometrically similar test-bars, and investigated the variation of the position of the elastic limit in overstrained bars. The "Mittheilungen," published under his direction, are a collection of extremely valuable and diversified researches.

It was due to Bauschinger's influence that an international association was formed in 1884 to discuss and standardise methods of testing.

Public Testing Laboratories.

In Germany, Austria, and Switzerland there are public laboratories, partly supported by the State, attached to technical high schools which are also Government institutions. Their function is to execute commissions for public departments or private persons. It was early recognised there that such laboratories can further industry and commerce, provided they meet the requirements of manufacturers, and at the same time are accepted as independent and impartial, and maintain a high standard of intelligence, accuracy, and skill. It is desirable that State institutions should carry out purely scientific investigations free of charge, but it is expected that private persons who use them should pay enough to cover outlay on special appliances or labour, while the cost of site, plant, and administration is borne by the State. It is possible for such institutions to follow out investigations suggested in the course of ordinary work which could not be attacked by private persons. In some cases industries have combined to have extensive researches, extending over years, made in these laboratories. The public make so much use of them that they are scarcely available any more for purposes of instruction. Thus in the engineering laboratory at Gross Lichterfelde there is a staff of 230 persons, of whom seventy-five have received high academic training, and thirty-eight others training in technical schools. The annual income from tests amounted in 1913 to 20,000*l*. and the expenditure to 32,000*l*.

The Bureau of Standards at Washington is a Government institution of the same type. It has four large laboratory buildings and four or five smaller buildings, which together cost 200,000*l*., and the equipment about 70,000*l*. The annual cost of maintenance is about 120,000*l*. There is also an auxiliary laboratory at Pittsburgh. Of six departments one is devoted to tests of materials and structures. A great deal of work is carried out for public departments, and the Bureau settles the specifications of materials supplied to them, as well as inspects and tests them. I understood when at Washington that the testing of the immense quantity of cement used on the Panama Canal was confided to the Bureau, but much work has also been done for manufacturers' associations and scientific societies.

The National Physical Laboratory is very similar to the Bureau of Standards, and has accomplished for this country similar work. It has now become a Government institution, and the continuance of its very valuable work is assured.

[The remainder of the lecture was concerned with testing machines and tests carried out with them.]

[18] "Experimental Inquiry into the Tensile Strength and other Properties of Wrought-iron and Steel," by D. Kirkaldy, 1862.

[19] J. J. Guest, "Strength of Ductile Materials under Combined Stress," Proc. Physical Soc., vol. xvii.; Scoble, *Phil. Mag.*, 1906, vol. xii.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

WE learn from *Science* that at a meeting of the General Municipal Council and the Chamber of Commerce at Bordeaux on September 10 a proposal was unanimously adopted to establish, in honour of the President of the United States, a Franco-American University of applied sciences, commerce, and industry.

THE regulations for the current academic year for technical schools and other forms of provision for higher education in England and Wales have now been issued by the Board of Education (Cd. 9152). Substantially the regulations are the same as those in force since August 1, 1915. It is satisfactory to find that the Board is prepared to increase its grants in any cases in which it is satisfied that, as a result of general increases since the financial year 1913–14 in the rates of salary or fees paid to teachers, the grant so determined has become an inadequate contribution towards the cost of the schools or classes concerned.

AT a recent meeting of the governors of the Royal Technical College, Glasgow, it was announced that 2368*l*. has been added to the New Endowment (Research) Fund, making the total to July 31 last 21,245*l*. Since then the college has received a donation of 1000*l*. from Sir William Rowan Thomson, and a similar sum from Mr. James Templeton, so that the fund now