has by modern research been thrown upon this disease, its pathology cannot be regarded as settled. See NUTRITION.

It ought to be mentioned that small quantities of sugar are frequently found in the urine in many diseases, and even in health after articles of food rich in sugar or starch have been eaten, as also in some forms of poisoning.

Little is known regarding the exciting causes of diabetes. Exposure to wet and cold, privation, depressing mental emotions, or mental overwork, the abuse of alcohol and of saccharine and starchy substances, have all been assigned as causes. It appears to be in some instances hereditary. It is most common among adults, and occurs much more frequently in males than in females.

The symptoms of diabetes are usually gradual in their onset, and the patient may suffer for a length of time before he thinks it necessary to apply for medical aid. The first symptoms which attract attention are failure of strength, and emaciation, along with great thirst and an increased amount and frequent passage of urine. From the normal quantity of from two to three pints in the twenty-four hours it may be increased to 10, 20, or 30 pints, or even more. It is usually of pale colour, and of thicker consistence than normal urine, possesses a decidedly sweet taste, and is of high specific gravity (1·03 to 1·05). It frequently gives rise to considerable irritation of the urinary passages.

By simple evaporation crystals of sugar may be obtained from diabetic urine, which also yields the characteristic chemical tests of sugar, while the amount of this substance can be accurately estimated by certain analytical processes. The quantity of sugar passed may vary from a few ounces to two or more pounds per diem, and it is found to be markedly increased after saccharine or starchy food has been taken. Sugar may also be found in the blood, saliva, tears, and in almost all the excretions of persons suffering from this disease. One of the most distressing symptoms is intense thirst, which the patient is constantly seeking to allay, the quantity of liquid consumed being in general enormous, and there is usually, but not invariably, a voracious appetite. The mouth is always parched, and a faint, sweetish odour may be evolved from the breath. The effect of the disease upon the general health is very marked, and the patient becomes more and more emaciated. He suffers from increasing muscular weakness, the temperature of his body is lowered, the skin is dry and harsh, the teeth are loosened or decay, while dyspeptic symptoms, constipation, and loss of sexual power are common accompaniments. There is in general great mental depression or irritability.

Diabetes as a rule advances comparatively slowly except in the case of young persons, in whom its progress is apt to be rapid. Various complications arise in the course of the disease, among which may be mentioned cataract, various cutaneous eruptions, kidney diseases, inflammatory chest affections, and especially pulmonary consumption, which is one of the most frequent modes of fatal termination in diabetes. Occasionally death occurs suddenly from exhaustion.

Diabetes is a very fatal form of disease, recovery being exceedingly rare. Nevertheless much may be done by appropriate treatment to mitigate the severity of the symptoms and to prolong life.

Cases may thus continue for years without material change to the worse, and in some rare instances it would seem that the disease is cured. The unfavourable cases are chiefly those occurring in young persons, also where serious chest or other complications arise, and especially where the disease itself is of severe character, the quantity of sugar passed being persistently large, and the patient losing flesh and strength rapidly.

With respect to the treatment of diabetes, the regulation of the diet has by all authorities been regarded as a matter of the first importance, inasmuch as it has been proved beyond question that certain kinds of food have a powerful influence in aggravating the disease, more particularly those consisting largely of saccharine and starchy matter; and it may be stated generally that the various methods of treatment proposed aim at the elimination as far as possible of these constituents from the diet. Hence it is recommended that such articles as bread, potatoes, and all farinaceous foods, turnips, carrots, parsnips, and most fruits should be avoided; while animal food and soups, green vegetables, milk, cream, cheese, eggs, butter, and tea and coffee without sugar, may be taken with advantage. As a substitute for ordinary bread, which most persons find it difficult to do without for any length of time, bran bread, gluten bread, almond biscuits, and even well-browned toast or rusks are recommended. Alcoholic stimulants are of little or no use, but if prescribed should be in those forms containing the least saccharine matter, such as claret, Burgundy, brandy, or bitter ale.

Thirst may be mitigated by iced water, or water slightly acidulated with phosphoric acid. The employment of a diet consisting entirely of skimmed milk has been recommended by Dr Donkin of London, who has obtained good results from this method of treatment. The milk is administered in quantities of from 8 to 12 pints in the twenty-four hours, all other articles of diet being excluded.

The plan of treatment once proposed, of administering sugar in large quantity in diabetes, proved to be highly injurious, and is now abandoned.

Numerous medicinal substances have been employed in diabetes, but few of them are worthy of mention as possessed of any efficacy. Opium is often found of great service, its administration being followed with marked amelioration in all the symptoms, and, according to some high authorities, with cure of the disease. It is borne in diabetes in larger doses than usual, and from 5 to 12 grains or more may be taken in the twenty-four hours. In like manner codeia (one of the constituents of opium), in doses of half a grain increased to two or three grains three times a day, has been used with good effect.

In most cases, however, it is the dieting of the patient to which the physician has to look in dealing successfully with this formidable disease; and sufferers ought always to be impressed with the necessity of strictly abstaining from those articles of food which by general consent are allowed to exercise a hurtful influence in aggravating the symptoms.

In *diabetes insipidus*, there is constant thirst and an excessive flow of urine, which, however, is not found to contain any abnormal constituent. Its effects upon the system are often similar to those of diabetes mellitus, except that they are much less marked, the disease being in general very slow in its progress. In some cases the health appears to suffer very slightly. It is rarely a direct cause of death, but from its debilitating effects may predispose to serious and fatal complications. Little is known as to its pathology, but it is generally supposed to own a similar origin to diabetes mellitus. It is best treated by tonics and generous diet. Opium and valerian have been found beneficial. (J. O. A.)

DIAGORAS, born at Melos, was a writer of dithyrambic poetry. Religious in his youth, he became an atheist because a great wrong done upon him (the details of which are unknown) was left unpunished by the gods. In consequence of his blasphemous speeches, and especially from his publication of the Mysteries, he was condemned to death at Athens, and a price set upon his head. During his flight he perished by shipwreck. Aristophanes alludes to his atheism in the *Clouds*, 830 *sqq.*, and to his condemnation in the *Birds*, 1073. His date is not exactly known. He could not have been, as is usually stated, a pupil of Democritus, as he was older than this philosopher, or certainly not younger. The circumstances of his death may have been confused with those of Protagoras. The writing in which he disclosed the Mysteries bore the name φρύγιοι λόγοι, or ἀποπυργίζοντες. These are all the facts which are known of him, and none of his actual opinions are preserved. See Zeller, *Geschichte der Griechischen Philosophie.*

DIAGRAMS. A diagram is a figure drawn in such a manner that the geometrical relations between the parts of the figure help us to understand relations between other objects. A few have been selected for description in this article on account of their greater geometrical significance.

Diagrams may be classed according to the manner in which they are intended to be used, and also according to the kind of analogy which we recognize between the diagram and the thing represented.

Diagrams of Illustration.

The diagrams in mathematical treatises are intended to help the reader to follow the mathematical reasoning. The construction of the figure is defined in words so that even if no figure were drawn the reader could draw one for himself. The diagram is a good one if those features which form the subject of the proposition are clearly represented. The accuracy of the drawing is therefore of smaller importance than its distinctness.

Metrical Diagrams.

Diagrams are also employed in an entirely different way —namely, for purposes of measurement. The plans and designs drawn by architects and engineers are used to determine the value of certain real magnitudes by measuring certain distances on the diagram. For such purposes it is essential that the drawing be as accurate as possible.

We therefore class diagrams as diagrams of illustration, which merely suggest certain relations to the mind of the spectator, and diagrams drawn to scale, from which measurements are intended to be made.

Methods in which diagrams are used for purposes of measurement are called Graphical methods.

Diagrams of illustration, if sufficiently accurate, may be used for purposes of measurement; and diagrams for measurement, if sufficiently clear, may be used for purposes of demonstration.

There are some diagrams or schemes, however, in which the form of the parts is of no importance, provided their connections are properly shown. Of this kind are the diagrams of electrical connections, and those belonging to that department of geometry which treats of the degrees of cyclosis, periphraxy, linkedness, and knottedness.

Diagrams purely Graphic and mixed Symbolic and Graphic.

Diagrams may also be classed either as purely graphical diagrams, in which no symbols are employed except letters or other marks to distinguish particular points of the diagrams, and mixed diagrams, in which certain magnitudes are represented, not by the magnitudes of parts of the diagram, but by symbols, such as numbers written on the diagram.

Thus in a map the height of places above the level of the sea is often indicated by marking the number of feet above the sea at the corresponding places on the map.

There is another method in which a line called a contour line is drawn through all the places in the map whose height above the sea is a certain number of feet, and the number of feet is written at some point or points of this line.

By the use of a series of contour lines, the height of a great number of places can be indicated on a map by means of a small number of written symbols. Still this method is not a purely graphical method, but a partly symbolical method of expressing the third dimension of objects on a diagram in two dimensions.

Diagrams in Pairs.

In order to express completely by a purely graphical method the relations of magnitudes involving more than two variables, we must use more than one diagram. Thus in the arts of construction we use plans and elevations and sections through different planes, to specify the form of objects having three dimensions.

In such systems of diagrams we have to indicate that a point in one diagram corresponds to a point in another diagram. This is generally done by marking the corresponding points in the different diagrams with the same letter. If the diagrams are drawn on the same piece of paper we may indicate corresponding points by drawing a line from one to the other, taking care that this line of correspondence is so drawn that it cannot be mistaken for a real line in either diagram.

In the stereoscope the two diagrams, by the combined use of which the form of bodies in three dimensions is recognized, are projections of the bodies taken from two points so near each other that, by viewing the two diagrams simultaneously, one with each eye, we identify the corresponding points intuitively.

The method in which we simultaneously contemplate two figures, and recognize a correspondence between certain points in the one figure and certain points in the other, is one of the most powerful and fertile methods hitherto known in science. Thus in pure geometry the theories of similar, reciprocal, and inverse figures have led to many extensions of the science. It is sometimes spoken of as the method or principle of Duality.

DIAGRAMS IN KINEMATICS.

The study of the motion of a material system is much assisted by the use of a series of diagrams representing the configuration, displacement, and acceleration of the parts of the system.

Diagram of Configuration.

In considering a material system it is often convenient to suppose that we have a record of its position at any given instant in the form of a diagram of configuration.

The position of any particle of the system is defined by drawing a straight line or vector from the origin, or point of reference, to the given particle. The position of the particle with respect to the origin is determined by the magnitude and direction of this vector.

If in the diagram we draw from the origin (which need not be the same point of space as the origin for the material system) a vector equal and parallel to the vector which determines the position of the particle, the end of this vector will indicate the position of the particle in the diagram of configuration.

If this is done for all the particles, we shall have a system of points in the diagram of configuration, each of which corresponds to a particle of the material system, and the relative positions of any pair of these points will be the same as the relative positions of the material particles which correspond to them.

We have hitherto spoken of two origins or points from which the vectors are supposed to be drawn—one for the material system, the other for the diagram. These points, however, and the vectors drawn from them, may now be omitted, so that we have on the one hand the material system and on the other a set of points, each point corresponding to a particle of the system, and the whole representing the configuration of the system at a given instant.

This is called a diagram of configuration.

Diagram of Displacement.

Let us next consider two diagrams of configuration of the same system, corresponding to two different instants.

We call the first the initial configuration and the second the final configuration, and the passage from the one configuration to the other we call the displacement of the system. We do not at present consider the length of time during which the displacement was effected, nor the intermediate stages through which it passed, but only the final result—a change of configuration. To study this change we construct a diagram of displacement.

Let A, B, C be the points in the initial diagram of configuration, and A′, B′, C′ be the corresponding points in the final diagram of configuration.

From o, the origin of the diagram of displacement, draw a vector oa equal and parallel to AA′, ob equal and parallel to BB′, oc to CC′, and so on.

The points, a, b, c, &c., will be such that the vector ab indicates the displacement of b relative to a, and so on. The diagram containing the points a, b, c, &c., is therefore called the diagram of displacement.

In constructing the diagram of displacement we have hitherto assumed that we know the absolute displacements of the points of the system. For we are required to draw a line equal and parallel to A_1A_2, which we cannot do unless we know the absolute final position of A, with respect to its initial position. In this diagram of displacement there is therefore, besides the points a, b, c, &c., an *origin*, o, which represents a point absolutely fixed in space. This is necessary because the two configurations do not exist at the same time; and therefore to express their relative position we require to know a point which remains the same at the beginning and end of the time.

But we may construct the diagram in another way which does not assume a knowledge of absolute displacement or of a point fixed in space.

Assuming any point and calling it a, draw ak parallel and equal to $B_1 A_1$ in the initial configuration, and from k draw kb parallel and equal to A_2B_2 in the final configuration. It is easy to see that the position of the point b relative to a will be the same by this construction as by the former construction, only we must observe that in this second construction we use only vectors such as A_1B_1, A_2B_2, which represent the relative position of points both of which exist simultaneously, instead of vectors such as A_1A_2, B_1B_2, which express the position of a point at one instant relative to its position at a former instant, and which therefore cannot be determined by observation, because the two ends of the vector do not exist simultaneously

It appears therefore that the diagram of displacements, when drawn by the first construction includes an origin o, which indicates that we have assumed a knowledge of absolute displacements. But no such point occurs in the second construction, because we use such vectors only as we can actually observe. Hence the diagram of displacements *without an origin* represents neither more nor less than all we can ever know about the displacement of the material system.

Diagram of Velocity.

If the relative velocities of the points of the system are constant, then the diagram of displacement corresponding to an interval of a unit of time between the initial and the final configuration is called a diagram of relative velocity.

If the relative velocities are not constant, we suppose another system in which the velocities are equal to the velocities of the given system at the given instant and continue constant for a unit of time. The diagram of displacements for this imaginary system is the required diagram of relative velocities of the actual system at the given instant.

It is easy to see that the diagram gives the velocity of any one point relative to any other, but cannot give the absolute velocity of any of them.

Diagram of Acceleration.

By the same process by which we formed the diagram of displacements from the two diagrams of initial and final configuration, we may form a diagram of changes of relative velocity from the two diagrams of initial and final velocities. This diagram may be called that of total accelerations in a finite interval of time.

By the same process by which we deduced the diagram of velocities from that of displacements we may deduce the diagram of rates of acceleration from that of total acceleration.

We have mentioned this system of diagrams in elementary kinematics because they are found to be of use especially when we have to deal with material systems containing a great number of parts, as in the kinetic theory of gases. The diagram of configuration then appears as a region of space swarming with points representing molecules, and the only way in which we can investigate it is by considering the number of such points in unit of volume in different parts of that region, and calling this the *density* of the gas.

In like manner the diagram of velocities appears as a region containing points equal in number but distributed in a different manner, and the number of points in any given portion of the region expresses the number of molecules whose velocities lie within given limits. We may speak of this as the velocity-density.

Path and Hodograph.

When the number of bodies in the system is not so great, we may construct diagrams each of which represents some property of the whole course of the motion.

Thus if we are considering the motion of one particle relative to another, the point on the diagram of configuration which corresponds to the moving particle will trace out a continuous line called the path of the particle.

On the diagram of velocity the point corresponding to the moving particle will trace another continuous line called the hodograph of the particle.

The hodograph was invented and used with great success by Sir W. R. Hamilton as a method of studying the motions of bodies.

DIAGRAMS OF STRESS.

Graphical methods are peculiarly applicable to statical questions, because the state of the system is constant, so that we do not need to construct a series of diagrams corresponding to the successive states of the system.

The most useful of these applications relates to the equilibrium of plane framed structures. Two diagrams are used, one called the diagram of the frame and the other called the diagram of stress.

The structure itself consists of a number of separable pieces or links jointed together at their extremities. In practice these joints have friction, or may be made purposely stiff, so that the force acting at the extremity of a piece may not pass exactly through the axis of the joint; but as it is unsafe to make the stability of the structure depend in any degree upon the stiffness of joints, we assume in our calculations that all the joints are perfectly smooth, and therefore that the force acting on the end of any link passes through the axis of the joint.

The axes of the joints of the structure are represented by points in the diagram of the frame.

The link which connects two joints in the actual structure may be of any shape, but in the diagram of the frame it is represented by a straight line joining the points representing the two joints.

If no force acts on the link except the two forces acting through the centres of the joints, these two forces must be equal and opposite, and their direction must coincide with the straight line joining the centres of the joints.

If the force acting on either extremity of the link is directed towards the other extremity, the stress on the link is called pressure and the link is called a strut. If it is directed away from the other extremity, the stress on the link is called tension and the link is called a tie.

In this case, therefore, the only stress acting in a link is a pressure or a tension in the direction of the straight line which represents it in the diagram of the frame, and all that we have to do is to find the magnitude of this stress.

In the actual structure, gravity acts on every part of the link, but in the diagram we substitute for the actual weight of the different parts of the link, two weights which have the same resultant acting at the extremities of the link.

We may now treat the diagram of the frame as composed of links without weight, but loaded at each joint with a weight made up of portions of the weights of all the links which meet in that joint.

If any link has more than two joints we may substitute for it in the diagram an imaginary stiff frame, consisting of links, each of which has only two joints.

The diagram of the frame is now reduced to a system of points, certain pairs of which are joined by straight lines, and each point is in general acted on by a weight or other force acting between it and some point external to the system.

To complete the diagram we may represent these external forces as links, that is to say, straight lines joining the points of the frame to points external to the frame. Thus each weight may be represented by a link joining the point of application of the weight with the centre of the earth.

But we can always construct an imaginary frame having its joints in the lines of action of these external forces, and this frame, together with the real frame and the links representing external forces, which join points in the one frame to points in the other frame, make up together a complete self-strained system in equilibrium, consisting of points connected by links acting by pressure or tension. We may in this way reduce any real structure to the case of a system of points with attractive or repulsive forces acting between certain pairs of these points, and keeping them in equilibrium.

The direction of each of these forces is sufficiently indicated by that of the line joining the points, so that we have only to determine its magnitude.

We might do this by calculation, and then write down on each link the pressure or the tension which acts in it.

We should in this way obtain a mixed diagram in which the stresses are represented graphically as regards direction and position, but symbolically as regards magnitude.

But we know that a force may be represented in a purely graphical manner by a straight line in the direction of the force containing as many units of length as there are units of force in the force. The end of this line is marked with an arrow head to show in which direction the force acts.

According to this method each force is drawn in its proper position in the diagram of configuration of the frame. Such a diagram might be useful as a record of the result of calculation of the magnitude of the forces, but it would be of no use in enabling us to test the correctness of the calculation.

But we have a graphical method of testing the equilibrium of any set of forces acting at a point. We draw in series a set of lines parallel and proportional to these forces. If these lines form a closed polygon the forces are in equilibrium. We might in this way form a series of polygons of forces, one for each joint of the frame. But in so doing we give up the principle of drawing the line representing a force from the point of application of the force, for all the sides of the polygon cannot pass through the same point, as the forces do.

We also represent every stress twice over, for it appears as a side of both the polygons corresponding to the two joints between which it acts.

But if we can arrange the polygons in such a way that the sides of any two polygons which represent the same stress coincide with each other, we may form a diagram in which every stress is represented in direction and magnitude, though not in position, by a single line which is the common boundary of the two polygons which represent the joints at the extremities of the corresponding piece of the frame.

We have thus obtained a pure diagram of stress in which no attempt is made to represent the configuration of the material system, and in which every force is not only represented in direction and magnitude by a straight line, but the equilibrium of the forces at any joint is manifest by inspection, for we have only to examine whether the corresponding polygon is closed or not.

The relations between the diagram of the frame and the diagram of stress are as follows:—

To every link in the frame corresponds a straight line in the diagram of stress which represents in magnitude and direction the stress acting in that link.

To every joint of the frame corresponds a closed polygon in the diagram, and the forces acting at that joint are represented by the sides of the polygon taken in a certain cyclical order. The cyclical order of the sides of the two adjacent polygons is such that their common side is traced in opposite directions in going round the two polygons.

The direction in which any side of a polygon is traced is the direction of the force acting on that joint of the frame which corresponds to the polygon, and due to that link of the frame which corresponds to the side.

This determines whether the stress of the link is a pressure or a tension.

If we know whether the stress of any one link is a pressure or a tension, this determines the cyclical order of the sides of the two polygons corresponding to the ends of the links, and therefore the cyclical order of all the polygons, and the nature of the stress in every link of the frame.

Definition of Reciprocal Diagrams.

When to every point of concourse of the lines in the diagram of stress corresponds a closed polygon in the skeleton of the frame, the two diagrams are said to be reciprocal.

The first extensions of the method of diagrams of forces to other cases than that of the funicular polygon were given by Rankine in his *Applied Mechanics* (1857). The method was independently applied to a large number of cases by Mr W. P. Taylor, a practical draughtsman in the office of the well-known contractor Mr J. B. Cochrane, and by Professor Clerk Maxwell in his lectures in King's College, London. In the *Phil. Mag.* for 1864 the latter pointed out the reciprocal properties of the two diagrams, and in a paper on "Reciprocal Figures, Frames, and Diagrams of Forces," *Trans. R. S. Edinburgh*, vol. xxvi. (1870), he showed the relation of the method to Airy's function of stress and to other mathematical methods.

Professor Fleeming Jenkin has given a number of applications of the method to practice (*Trans. R. S. Edin.*, vol. xxv.)

Cremona (*Le figure reciproche nella statica grafica*, Milan, 1872) has deduced the construction of reciprocal figures from the theory of the two components of a wrench as developed by Möbius.

Culmann, in his *Graphische Statik*, makes great use of diagrams of forces, some of which, however, are not reciprocal.

M. Maurice Levy in his *Statique Graphique* (Paris, 1874) has treated the whole subject in an elementary but copious manner.

Mr R. H. Bow, C.E., F.R.S.E., in his work on *The Economics of Construction in relation to Framed Structures*, 1873, has materially simplified the process of drawing a diagram of stress reciprocal to a given frame acted on by a system of equilibrating external forces.

Instead of lettering the joints of the frame as is usually done, or the links of the frame, as was the writer's custom, he places a letter in each of the polygonal areas inclosed by the links of the frame, and also in each of the divisions of surrounding space as separated by the lines of action of the external forces.

When one link of the frame crosses another, the point of apparent intersection of the links is treated as if it were a real joint, and the stresses of each of the intersecting links are represented twice in the diagram of stress, as the opposite sides of the parallelogram which corresponds to the point of intersection.

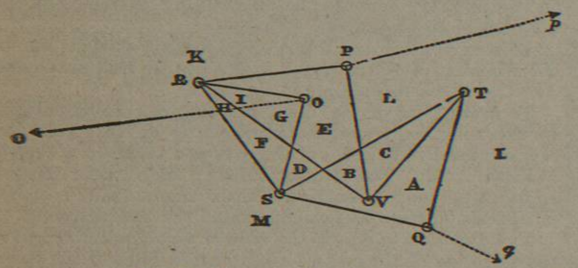

FIG. 1.—Diagram of Configuration.

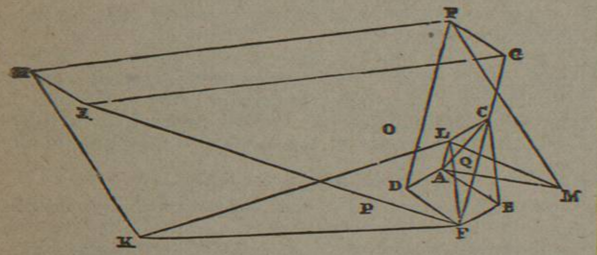

FIG. 2.—Diagram of Stress.

This method is followed in the lettering of the diagram of configuration (fig. 1), and the diagram of stress (fig. 2) of the linkwork which Professor Sylvester has called a quadruplane.

In fig. 1 the real joints are distinguished from the places where one link appears to cross another by the little circles O, P, Q, R, S, T, V.

The four links RSTV form a "contraparallelogram" in which RS = TV and RV = ST.

The triangles ROS, RPV, TQS are similar to each other. A fourth triangle (TNV), not drawn in the figure, would complete the quadruplane. The four points O, P, N, Q form a parallelogram whose angle POQ is constant and equal to π − SOR. The product of the distances OP and OQ is constant.

The linkwork may be fixed at O. If any figure is traced by P, Q will trace the inverse figure, but turned round O through the constant angle POQ.

In the diagram forces Pp, Qq are balanced by the force Oo at the fixed point. The forces Pp and Qq are necessarily inversely as OP and OQ, and make equal angles with those lines.

Every closed area formed by the links or the external forces in the diagram of configuration is marked by a letter which corresponds to a point of concourse of lines in the diagram of stress.

The stress in the link which is the common boundary of two areas is represented in the diagram of stress by the line joining the points corresponding to those areas.

When a link is divided into two or more parts by lines crossing it, the stress in each part is represented by a different line for each part, but as the stress is the same throughout the link these lines are all equal and parallel. Thus in the figure the stress in RV is represented by the four equal and parallel lines HI, FG, DE, and AB.

If two areas have no part of their boundary in common the letters corresponding to them in the diagram of stress are not joined by a straight line. If, however, a straight line were drawn between them, it would represent in direction and magnitude the resultant of all the stresses in the links which are cut by any line, straight or curved, joining the two areas.

For instance the areas F and C in fig. 1 have no common boundary, and the points F and C in fig. 2 are not joined by a straight line. But every path from the area F to the area C in fig. 1 passes through a series of other areas, and each passage from one area into a contiguous area corresponds to a line drawn in the diagram of stress. Hence the whole path from F to C in fig. 1 corresponds to a path formed of lines in fig. 2 and extending from F to C, and the resultant of all the stresses in the links cut by the path is represented by FC in fig. 2.

Automatic Description of Diagrams.

There are many other kinds of diagrams in which the two co-ordinates of a point in a plane are employed to indicate the simultaneous values of two related quantities.

If a sheet of paper is made to move, say horizontally, with a constant known velocity, while a tracing point is made to move in a vertical straight line, the height varying as the value of any given physical quantity, the point will trace out a curve on the paper from which the value of that quantity at any given time may be determined.

This principle is applied to the automatic registration of phenomena of all kinds, from those of meteorology and terrestrial magnetism to the velocity of cannon-shot, the vibrations of sounding bodies, the motions of animals, voluntary and involuntary, and the currents in electric telegraphs.

Indicator Diagram.

In Watt's indicator for steam engines the paper does not move with a constant velocity, but its displacement is proportional to that of the piston of the engine, while that of the tracing point is proportional to the pressure of the steam. Hence the co-ordinates of a point of the curve traced on the diagram represent the volume and the pressure of the steam in the cylinder. The indicator-diagram not only supplies a record of the pressure of the steam at each stage of the stroke of the engine, but indicates the work done by the steam in each stroke by the area inclosed by the curve traced on the diagram.

The indicator-diagram was invented by James Watt as a method of estimating the work done by an engine. It was afterwards used by Clapeyron to illustrate the theory of heat, and this use of it was greatly developed by Rankine in his work on the steam engine.

The use of diagrams in thermodynamics has been very completely illustrated by Prof. J. Willard Gibbs (*Connecticut Acad. Sci.*, vol. iii.), but though his methods throw much light on the general theory of diagrams as a method of study, they belong rather to thermodynamics than to the present subject. (J. C. M.)

DIALLING

DIALLING, sometimes called gnomonics, is a branch of applied mathematics which treats of the construction of sun-dials, that is, of those instruments, either fixed or portable, which determine the divisions of the day by the motion of the shadow of some object on which the sun's rays fall.

It must have been one of the earliest applications of a knowledge of the apparent motion of the sun; though for a long time men would probably be satisfied with the division into morning and afternoon as marked by sun-rise, sun-set, and the greatest elevation.

History.—The earliest mention of a sun-dial is found in Isaiah xxxviii. 8: "Behold, I will bring again the shadow of the degrees which is gone down in the *sun-dial* of Ahaz ten degrees backward." The date of this would be about 700 years before the Christian era, but we know nothing of the character or construction of the instrument.

The earliest of all sun-dials of which we have any certain knowledge was the hemicycle, or hemisphere, of the Chaldean astronomer Berosus, who probably lived about 340 B.C. It consisted of a hollow hemisphere placed with its rim perfectly horizontal, and having a bead, or globule, fixed in any way at the centre. So long as the sun remained above the horizon the shadow of the bead would fall on the inside of the hemisphere, and the path of the shadow during the day would be approximately a circular arc. This arc, divided into twelve equal parts, determined twelve equal intervals of time for that day. Now, supposing this were done at the time of the solstices and equinoxes, and on as many intermediate days as might be considered sufficient, and then curve lines drawn through the corresponding points of division of the different arcs, the shadow of the bead falling on one of these curve lines would mark a division of time for that day, and thus we should have a sun-dial which would divide each period of daylight into twelve equal parts.

These equal parts were called *temporary hours;* and, since the duration of daylight varies from day to day, the temporary hours of one day would differ from those of another; but this inequality would probably be disregarded at that time, and especially in countries where the variation between the longest summer day and the shortest winter day is much less than in our climates.

The dial of Berosus remained in use for centuries. The Arabians, as appears from the work of Albategnius, still followed the same construction about the year 900 A.D. Four of these dials have in modern times been found in Italy. One, discovered at Tivoli in 1746, is supposed to have belonged to Cicero, who, in one of his letters, says that he had sent a dial of this kind to his villa near Tusculum. The second and third were found in 1751—one at Castel-Nuovo, and the other at Rignano; and a fourth was found in 1762 at Pompeii. G. H. Martini, the author of a dissertation in German on the dials of the ancients, says that this dial was made for the latitude of Memphis; it may therefore be the work of Egyptians, perhaps constructed in the school of Alexandria.

It is curious that no sun-dial has been found among the antiquities of Egypt, and their sculptures give no indication of any having existed. It has, however, been supposed that the numerous obelisks found everywhere were erected in honour of the sun and employed as gnomons.

Herodotus has recorded that the Greeks derived from the Babylonians the use of the gnomon, but the great progress made by the Greeks in geometry enabled them in later times to construct dials of great complexity, some of which remain to us, and are proofs, not only of extensive knowledge, but also of great ingenuity.

Ptolemy's *Syntaxis* treats of the construction of dials by means of his *analemma*, an instrument which solved a variety of astronomical problems. The constructions given by him were sufficient for regular dials, that is, horizontal dials, or vertical dials facing east, west, north, or south, and these are the only ones he treats of. It is certain, however, that the ancients were able to construct declining dials, as is shown by that most interesting monument of ancient gnomonics—the Tower of the Winds—which is still in existence at Athens. This is a regular octagon, on the faces of which the eight principal winds are represented, and over them eight different dials—four facing the cardinal points and the other four facing the intermediate directions. The date of the dials is long subsequent to that of the tower; for Vitruvius, who describes the tower in the sixth chapter of his first book, says nothing about the dials, and as he has described all the dials known in his time, we must believe that the dials of the tower did not then exist. The tower and its dials are described by Stuart in his *Antiquities of Athens*. The hours are still the temporary hours, or, as the Greeks called them, *hectemoria*.

As already stated, the learning and ingenuity of the Greeks enabled them to construct dials of various forms—among others, dials of suspension intended for travellers; but these are only spoken of and not explained; they may have been like our ring-dials.

The Romans were neither geometers nor astronomers, and the science of gnomonics did not flourish among them. The first sun-dial erected at Rome was in the year 290 B.C., and this Papirius Cursor had taken from the Samnites. A dial which Valerius Messala had brought from Catania, the latitude of which is five degrees less than that of Rome, was placed in the forum in the year 261 B.C. The first dial actually constructed at Rome was in the year 164 B.C., by order of Q. Marcius Philippus, but, as no other Roman has written on gnomonics, this was perhaps the work of a foreign artist. If, too, we remember that the dial found at Pompeii was made for the latitude of Memphis, and consequently less adapted to its position than that of Catania to Rome, we may infer that mathematical knowledge was not cultivated in Italy.

The Arabians were much more successful. They attached great importance to gnomonics, the principles of which they had learned from the Greeks, but they greatly simplified and diversified the Greek constructions. One of their writers, Abul-Hassan, who lived about the beginning of the 13th century, taught them how to trace dials on cylindrical, conical, and other surfaces. He even introduced *equal* or *equinoctial hours*, but the idea was not supported, and the temporary hours alone continued in use.

Where or when the great and important step already conceived by Abul-Hassan. and perhaps by others, of reckoning by *equal* hours was generally adopted cannot now be determined. The history of gnomonics from the 13th to the beginning of the 16th century is almost a blank, and during that time the change took place. We