vigorous Doric phraseology fast passing out of use even in country districts. In this novel Mr Galt used, for the first time, the term "Utilitarian," which has since become so intimately associated with the doctrines of John Stuart Mill and his followers (see *Annals of the Parish*, chap. xxxv., and a note by Mr Mill in *Utilitarianism*, chap. ii.). In *Sir Andrew Wylie* the hero entered London as a poor lad, but achieved remarkable success by his shrewd business qualities. The character is somewhat exaggerated, but excessively amusing. *The Entail* was read thrice by Byron and Scott, and is the best of Galt's longer novels. Leddy Grippy is a wonderful creation, and was considered by Byron equal to any female character in literature since Shakespeare's time. *The Provost*, in which Provost Pawkie tells his own story, portrays inimitably the jobbery, bickerings, and selfseeking of municipal dignitaries in a quaint Scottish burgh. In *Lawrie Todd* Galt, by giving us the Scot in America, has accomplished a feat which Sir Walter never attempted. This novel exhibits more variety of style and a greater love of nature than his other books. The life of a settler is depicted with unerring pencil, and with an enthusiasm and imaginative power much more poetical than any of the author's professed poems.

Galt's humour is broader and more contagious than Scott's; and his pictures of the sleepy life of old Scottish towns are unrivalled in literature. He is generally called an imitator of Scott; but the *Annals of the Parish* existed in MS. before *Waverley* was published. As Galt is pre-eminently an illustrator of west-country Scottish life, his range may be said to be narrower than Scott's; but within it he is supreme. It would be difficult to overrate the immense services which Galt has rendered alike to the history of the manners and to the history of the language of the Scottish people.

For further information about Galt, see his *Autobiography*; *The Literary Life of John Galt*; and a biographical memoir by his friend the late Dr Moir of Musselburgh, prefixed to *The Annals of the Parish*. (T. GI.)

GALOIS, Evariste (1811–1832), an eminently original and profound French mathematician, born 26th October 1811, killed in a duel May 1832. A necrological notice by his friend M. Auguste Chevalier appeared in the *Revue Encyclopédique*, September 1832, p. 744; and his collected works are published, *Lionville*, t. xi. (1846), pp. 381–444, about fifty of these pages being occupied by researches on the resolubility of algebraic equations by radicals. But these researches, crowning as it were the previous labours of Lagrange, Gauss, and Abel, have in a signal manner advanced the theory, and it is not too much to say that they are the foundation of all that has since been done, or is doing, in the subject. The fundamental notion consists in the establishment of a group of permutations of the roots of an equation, such that every function of the roots invariable by the substitutions of the group is rationally known, and reciprocally that every rationally determinable function of the roots is invariable by the substitutions of the groups; some further explanation of the theorem, and in connexion with it an explanation of the notion of an adjoint radical, is given under Equation, No. 32. As part of the theory (but the investigation has a very high independent value as regards the Theory of Numbers, to which it properly belongs), Galois introduces the notion of the imaginary roots of an irreducible congruence of a degree superior to unity; *i.e.*, such a congruence, $F(x) \equiv 0$ (mod. a prime number p), has no integer root; but what is done is to introduce a quantity i subjected to the condition of verifying the congruence in question, $F(i) \equiv 1$ (mod. p), which quantity i is an imaginary of an entirely new kind, occupying in the theory of numbers a position analogous to that of $-\sqrt{-1}$ in algebra.

GALUPPI, Baldassarre (1706–1785), a musical composer, was born in 1706, in the island of Burano, near Venice. His father, a barber by profession, was a musical amateur, and prepared his son for the music school of Venice called Conservatorio degl' Incurabili, where the great Lotti became his master. His first opera, written at the age of sixteen, was a failure; but his comic opera named *Dorinda*, produced seven years later, was a great success, and laid the foundation of the youthful composer's fame. He was a prolific writer, and no less than seventy of his operas are enumerated, none of which, however, have kept the stage. Some of these were written for London, where Galuppi resided between 1741 and 1744, but his masterpiece in tragic opera was produced at St Petersburg in 1766. The composer had been induced by liberal offers to accept a position as imperial conductor of music, and to leave his native country for Russia, where he lived in high honour at the court of the czar, and is said to have in return done much for the progress of his art in Russia by introducing amongst other things Italian church-music. In 1768 he left Russia, and resumed his position as organist of the cathedral of St Mark at Venice, to which he had been appointed in 1762, and which had been kept open for him during his absence. He died in 1785, and left 50,000 lire to the poor of Venice. His best comic opera bears the title *Il mondo della luna*. The libraries of Dresden and Vienna preserve several of his operas in MS. At Vienna also some of his works of sacred music may be found. Others are in Paris and Rome.

GALVANI, Luigi (1737–1798), an eminent Italian physiologist, after whom galvanism received its name, was born at Bologna, September 9, 1737. It was his wish in early life to enter the church, but by his parents he was educated for a medical career. At the university of Bologna, in which city he practised, he was in 1762 appointed public lecturer in anatomy, and soon gained repute as a skilled though not eloquent teacher, and, chiefly from his researches on the organs of hearing and genito-urinary tract of birds, as a comparative anatomist. His celebrated theory of animal electricity he enunciated in a treatise, "De viribus electricitatis in motu musculari commentarius," published in the 8th volume of the memoirs of the Institute of Sciences at Bologna in 1791, and separately at Modena in the following year, and elsewhere subsequently. The statement has frequently been repeated that, in 1786, Galvani had skinned some frogs to make broth for his wife, who was in delicate health; that the leg of one of these, on being accidentally touched by a scalpel which had lain near an electrical machine, was thrown into violent convulsions; and that it was thus that his attention was first directed to the relations of animal functions to electricity. From documents in the possession of the Institute of Bologna, however, it appears that twenty years previous to the publication of his *Commentary* Galvani was already engaged in investigations as to the action of electricity upon the muscles of frogs. The observation that the suspension of certain of these animals on an iron railing by copper hooks caused twitching in the muscles of their legs led him to the invention of his metallic arc, the first experiment with which is described in the third part of the *Commentary*, wherein it is registered September 20, 1786. The arc he constructed of two different metals, which, placed in contact the one with a nerve and the other with a muscle of a frog, caused contraction of the latter. In Galvani's view the motions of the muscle were the result of the union, by means of the metallic arc, of its exterior or negative electrical charge with positive electricity which proceeded along the nerve from its inner substance. Volta, on the other hand, attributed them solely to the effect of electricity having its source in the junction of the two dissimilar metals of the arc, and regarded the nerve and muscle simply as conductors. Galvani in one of his memoirs recorded the observation that muscular contractions may be caused in a prepared frog merely by bending back the legs and bringing them into contact with the lumbar nerves, as also when a nerve is touched at two different points with a morsel of muscle taken from a living frog, phenomena not satisfactorily explicable on the theories of Volta; but after the death of the Bologna professor very little was heard of animal electricity till, in 1827, the study of the subject was resumed by Nobili. On Galvani's refusal, from religious scruples, to take the oath of allegiance to the Cisalpine republic on its establishment, he was removed from his professorship. Deprived thus of the means of livelihood, he retired to the house of his brother Giacomo, where he soon fell into a feverish decline. The republican Government, in consideration of his great scientific fame, eventually, but too late, determined to reinstate him in his chair at the university of Bologna. He died December 4, 1798. A quarto edition of his works was published at Bologna in 1841–42, by the Academy of Sciences of the Institute of that city, under the title *Opere edite ed inedite del professore Luigi Galvani*.

See Volta, "An Account of some Discoveries made by Mr Galvani, of Bologna," in *Phil. Trans.*, 1793, pp. 10–44; J. L. Alibert, *Elogio Storico di Luigi Galvani, Traduzione dal Francese*, Bolog., 1802, fol.; Arago, in "Alexandre Volta," *Œuvres Complètes*, ed. Barral, t. i. p. 242, 1854; and H. M. Noad, *Manual of Electricity*, chap. x.; also Electricity, vol. viii. p. 9, col. 1, and Volta.

GALVANISM. See Electricity and Physiology.

GALVANOMETER, an instrument used for indicating or measuring currents of electricity, wherein advantage is taken of the force exerted by such currents on movable magnets in their neighbourhood.[1] When a galvanometer is used for indicating merely, without measuring, it is sometimes called a galvanoscope. If we consider only such instruments as have come into actual use, this definition is strict enough for practical purposes. If we were to consider all the instruments that have been or might be made, some would come under the definition whose resemblance to the modern galvanometer would not at first sight be apparent. Such, for instance, is the electromagnetic balance of Becquerel,[2] which consists of two bar magnets hung from the scale pans of a delicate balance each in the axis of a cylindrical bobbin of wire—one being over, the other under its corresponding bobbin (see fig. 1). The north poles of both magnets hang downwards, and the current to be measured is sent round the bobbin, so that each of the magnets is repelled. Weights are put into the left-hand scale until equilibrium in the original position is restored. The weight thus added is proportional to the current strength, so long as the induced magnetism of the magnets can be neglected. This instrument has fallen into disuse.

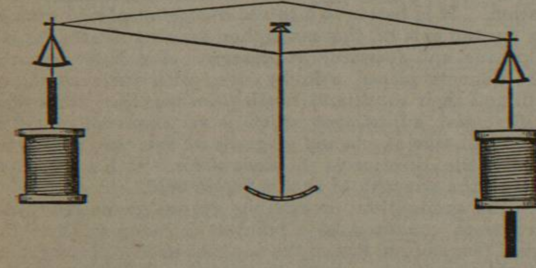

Fig. 1.

In a complete galvanometer of modern construction the following parts may occur:—(1) the coil or multiplier, (2) the needle or movable magnet or magnets, (3) the astatizing apparatus, (4) the deflecting or adjusting magnet, (5) the graduation or reading apparatus, (6) the damping apparatus, (7) accompanying the galvanometer, as a piece of auxiliary apparatus, we may also have a box of shunts. It would be easy to make a more minute enumeration of parts, but the above will serve our present purpose. On the other hand, it is not always that each of the above organs is represented separately; some may be wanting in certain cases, and the functions of two or more may be combined.

1. The multiplier or coil consists of a ring-shaped channel of elliptical, rectangular, or circular shape—usually the last, the cross section being in general rectangular. Into this is wound, as closely and regularly as possible, a quantity of silk-covered wire. The material chosen for the wire is usually copper, which should be as soft as possible in order to secure high conductivity. White silk is preferred for the insulating covering, on account of its freedom from iron, though this is for most purposes a needless refinement. Great care should be taken that the wire is dry when it is wound. It is usual, in order to secure and render permanent the insulation, to steep the whole coil in melted paraffin; after this has been done, there is little risk of loss of insulation, provided the layers have been carefully tested during the winding. The idea of the multiplier in sensitive galvanometers is to bring the greatest number of coils of wire within the least possible distances of the magnet. It is evident, therefore, that the insulating covering should be as thin as is consistent with good insulation; this consideration assumes great importance when coils of very fine wire have to be wound. After the wire has reached a certain fineness the proportion of space occupied by insulating matter is so great that further reduction of the section of the wire simply increases the resistance without enabling us to pack more turns into the same space. In general the section of the wire ought to be chosen with reference to the use which the galvanometer is intended to serve. The following ideal case will enable the reader to comprehend the principle which regulates the choice of multiplier under given circumstances. Suppose the dimensions of the channel, and the whole space which the wire is to fill, to be given, and the whole external resistance also given, then it may be shown that the section of the wire[3] ought to be chosen so that the resistance of the galvanometer shall be equal to the external resistance. The case contemplated here is that where we have a simple external circuit; many cases can be reduced to this at once, and we shall consider below a more complicated case of considerable practical importance. Theoretically the section of the wire ought to vary with the distance of the winding from the axis of the coil. The law is that the diameter of the wire in each layer ought to be proportional to the linear dimension of that layer. This is sometimes roughly carried out in practice by winding the outer layers of thicker wire than the inner.[4] The proper form of the longitudinal section of the coil depends on the use for which the instrument is destined, and will be more properly discussed when we describe particular instruments. In a certain class of galvanometers called differential, the wire on the coil is wound double, so that two currents can be sent through side by side in the same or in opposite directions.

2. The needle consists of a piece of magnetized steel,

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[1] For another definition see the article Electrometer.

[2] For a brief history of the construction of galvanometric apparatus see art. Electricity, vol. viii. p. 13.

[3] In this and all that follows the silk covering is either neglected or is supposed to vary in thickness as the diameter of the wire.

[4] The cross section of the coil is not a matter of indifference in sensitive galvanometers; but the question is hardly of sufficient importance to need discussion here. Information on the subject will be found in W. Weber's *Electrodynamische Maasbestimmungen*, Thl. ii.; H. Weber, *Pogg. Ann.*, 1869; Maxwell's *Electricity and Magnetism*, vol. ii. secs. 716 *sqq.*: Jenkin's *Electricity and Magnetism*, cap. xiii. sec. 9.

which should be as hard as possible. Watch-spring steel is sometimes used, and file steel is recommended by some authorities. The hardness is important for two reasons,—in the first place, to ensure that the permanent magnetism of the needle shall not alter. This is of small importance where permanent deflections are to be observed, provided we can be sure that the direction of the magnetic axis does not alter. In the second place the induced magnetism is less in hard than in soft steel, though not so much less as some writers would lead us to suppose. The best way of avoiding induced magnetism would be to make the needle spherical in form; the advantage thus gained, however, would in most cases be counterbalanced by other defects.

The form of the needle has been much varied by different constructors. In the earlier instruments they were made very long, and were suspended like compass needles by means of a jewelled cup playing on a steel point. We have heard on good authority that for some purposes, such as mounting tangent galvanometer needles, this method of suspension, if carefully carried out, really answers very well. By far the most usual mode of suspension, however, is by means of a raw silk fibre, or by a bundle of such fibres. Weber introduced the use of heavy magnets whose moment of inertia and time of oscillation were great. For many purposes such needles have great advantages—where, for instance, the time of oscillation, the logarithmic decrement, or the extent of swing of the needle has to be observed. Where, on the contrary, the galvanometer is to be used merely as an indicator, particularly in detecting transient currents, a light needle of small moment of inertia should be used. Continental constructors, no doubt unduly influenced by a reverence for Weber's methods, have failed to realize this; and we have seen few, if indeed any, instruments by them really well suited for measuring resistances with the Wheatstone's bridge. This principle has been carried farthest in the galvanometers of Sir William Thomson, in some of which the needle with all its appurtenances weighs little over a grain.

In some galvanometers (*e.g.*, certain telegraphic reading instruments) the needle is movable about a horizontal axis, and is weighted so as to be vertical in its undisturbed position. Owing to the friction at the points where the axis is supported, this method of suspension is useless for sensitive instruments.

3. When, as is usual, the galvanometer magnet is movable in a horizontal plane, the force which balances the electromagnetic force of the current in the multiplier is the horizontal component of the earth's magnetic force. Each of these forces is proportional to the magnetic moment of the galvanometer needle, and consequently the ratio of the forces, on which depends the magnitude of the deflexion of the needle, is independent of the magnetic moment of the needle. We cannot therefore increase the sensitiveness of the galvanometer by simply increasing the magnetic moment of the needle. The action of the earth can, however, be counteracted, and the needle rendered more or less *astatic* in one or other of two ways.

One way is to fix on the same axis of suspension two parallel magnets, whose magnetic moments are as nearly as possible equal, and which are turned opposite ways. The whole system is suspended so that one of the magnets swings inside the multiplier and the other over it, as in fig. 2. In more modern instruments, such as those constructed by Messrs Elliot Brothers, the multiplier consists of two equal coils placed one vertically over the other, each enclosing one of the magnets of the astatic system, as in fig. 3. Another method is to place a magnet, or a system of magnets, in the neighbourhood of the galvanometer, so as to counteract the earth's force. In general, one magnet will suffice, placed vertically under or over the galvanometer, in the magnetic meridian, its north pole of course pointing north. For convenience this magnet should be mounted on a vertical graduated rod, with a rough and a fine adjustment.

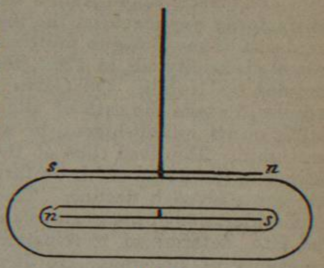

Fig. 2.

In adjusting the sensitiveness of the galvanometer, it will be useful to recollect that the couple tending to bring the needle back to its position of equilibrium varies directly as the square of the number of oscillations which the needle executes in a given time when no current is passing through the multiplier.[1] As the astatizing magnet is brought nearer and nearer to the galvanometer, the oscillations of the needle will be seen to become slower and slower, till at last the equilibrium becomes unstable, and the needle turns round through 180°; after which, on causing the magnet to approach still farther, the rapidity of oscillation increases. If the damping be very strong, and the mirror very light, an intermediate stage called the *aperiodic* state is passed through.

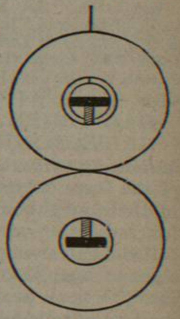

Fig. 3.

4. The normal position of the magnetic axis of the needle, when no current is passing, is parallel to the windings of the multiplier. It is particularly necessary that it should be in this position when the galvanometer is being used as a measuring instrument, and it is advisable in any case, since this is the position in which for a given current the electromagnetic action on the needle is greatest. The final adjustment might of course be made by moving the multiplier, but it is far more convenient to move the needle, a magnet being used for the purpose. Sometimes the astatizing magnet is used, but it is better to have a much weaker magnet for the fine adjustment, suspended like the astatizer on a vertical axis, having a vertical motion and a motion of rotation. It is better still to use a magnet placed with its axis in the axis of the multiplier, so that it can be slid backwards and forwards at pleasure. We have seen two such magnets placed side by side, with their north and south and their south and north poles together; this gives a differential adjustment which is very convenient. The main advantage of placing magnets in this way is that we can alter the direction of the lines of force with a minimum effect on the strength of the magnetic field.

5. The graduation or reading apparatus in the older instruments consisted of a pointer or index fixed to the magnet (very often it was the magnet itself), playing over a circular graduation centred as nearly as possible in the axis of rotation of the needle. The mirror method of reading which prevails in most modern instruments was originally suggested by Poggendorff, and carried out in practice by Gauss and Weber. A mirror is rigidly attached to the magnet, so that the reflecting face passes as nearly as possible through the vertical axis of rotation of the needle. The glass of the mirror should be very thin, otherwise a greater or less correction for its thickness will be necessary. In the *subjective* method of reading, a scale is fixed before the mirror, which is usually plane (it must be well made to be of any use), and the image of the scale is observed by means of a telescope fixed over or under the centre of the scale. The scale divisions are seen to pass the wires of the telescope, and if a circular scale be used, whose centre is in the axis of suspension of the mirror, the difference between the numbers on the cross wires in any two positions of the magnet is a measure of twice the deflection of the magnet. A correction is necessary when a straight scale is used. The reader who has occasion to use the method will find practical instructions, with tables of corrections, in Wiedemann's *Galvanismus*, Bd. ii. sec. 181 *sqq.*; Maxwell's *Electricity and Magnetism*, vol. ii. sec. 450 *sqq.* In the *objective* method, which is more usually practised in this country, the mirror is concave, and reflects the image of a fixed illuminated slit (often furnished with a vertical wire where greater accuracy is desired) upon a graduated scale. The readings are proportional to double the deflexion of the needle, or to the tangent of the double deflexion, according as the scale is circular or straight.

6. By damping is meant the decrease of the extent of the oscillations of the galvanometer needle arising from the dissipation of energy through the resistance of the air, the action of currents induced in neighbouring metallic circuits, the viscosity of the suspension fibre, and so on. There is always more or less damping owing to the first two causes, and possibly the third; but in many cases, where it is desirable that the oscillations should subside very quickly, the damping is purposely increased. In the older instruments the damping arrangement consisted of masses of copper surrounding the magnet. This is carried to the extreme in Wiedemann's tangent galvanometer, where the needle is ring-shaped, and swings in a ring-shaped cavity not much larger than itself, in the heart of a mass of copper. In the dead-beat galvanometers of Sir William Thomson the magnet with its attached mirror is enclosed in a flat cell, in which it can just move freely to the required extent. The damping, due to the pumping of the air backwards and forwards round the edges of the mirror, is so great that the needle swings off to its position of equilibrium, and remains there without oscillating at all. The same result is attained in Varley's construction by immersing the needle in a cell filled with liquid.

7. The box of shunts is simply a set of resistances; generally there are three,—$\frac{1}{9}$th, $\frac{1}{99}$th, and $\frac{1}{999}$th of the resistance of the multiplier When it is required to reduce the sensibility of the galvanometer, the terminals of one of these, say the $\frac{1}{99}$th, are connected with the terminals of the multiplier; we thus have a multiple arc in place of the galvanometer, and the current is divided between its branches in the ratio of their conductivities, so that one-hundredth[1] of the whole current flows through the galvanometer. By means of such a box as we have described, we can therefore send through the galvanometer the whole of any current, or the tenth, hundredth, or thousandth part. It must not be forgotten that the introduction of the shunt diminishes the whole resistance of the galvanometer circuit. In most cases, however, this is of little moment; where necessary, the alteration may be either compensated[2] or allowed for.

Sensitive Galvanometers.—In galvanometers of this class everything is disposed so as to bring the greatest possible number of turns of wire into the neighbourhood of the needle. The needle is therefore made as small and compact as possible, and the windings embrace it as closely as possible, the opening in the centre of the coil being reduced to a minimum. The astatic multiplier (fig. 4) is an instrument of this kind which was formerly much used. The coil is of flat, rectangular shape, with a narrow central opening just large enough to allow one of the magnets of the astatic system to swing freely. The other magnet swings over a graduated circle placed on the top of the coil, and serves also as an index. Sometimes a mirror and scale are substituted for the index and graduated circle. The sole on which the coil stands is movable on a fixed piece which can be levelled by means of three screws. A graduation is often furnished to measure the angle of rotation of the coil about a vertical axis; this is useful when the galvanometer has to be graduated or corrected for the torsion of the fibre.

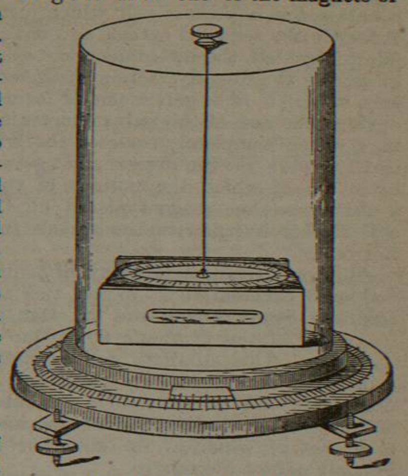

FIG. 4.—Astatic multiplier.

In the galvanometers of Sir William Thomson, which are the most sensitive hitherto constructed, the central opening of the coil is circular, being just large enough to allow free play to a small concave mirror a centimetre or so in diameter. Usually the coil is wound in two halves, which can be screwed together with a septum between them, in which is placed the arrangement for suspending the mirror and magnets. In dead-beat instruments the coil is often wound in a single piece, and the mirror is arranged in a cell,[3] glazed back and front, and fitted into a tube which slides into the core of the coil.

Fig. 5 represents a very convenient form of Thomson's galvanometer, the only specimen of its kind we have seen. The peculiarity of its construction consists in the connexion between the scale and the galvanometer, which saves much trouble in adjusting the instrument. It was constructed by Elliot Brothers for the British Association Committee on Electrical Standards. Such a galvanometer as this, provided with a high and low resistance coil, would meet all the wants of most laboratories.

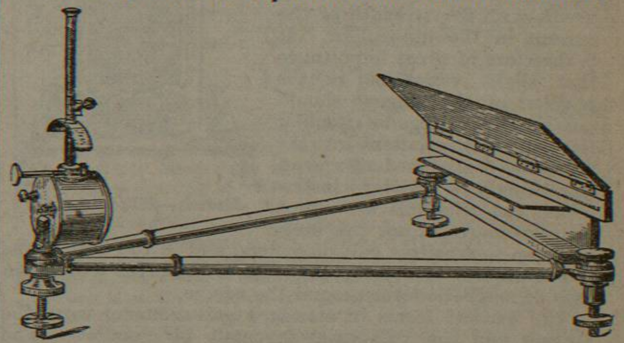

FIG. 5.—Form of Thomson's Galvanometer.

In another form called the marine galvanometer, the mirror is strung on a fibre stretched between two fixed points. In order to keep the needle from being influenced

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[1] This is not exactly true where there is damping: but the rule is sufficient for ordinary purposes.

[1] See art. ELECTRICITY, p. 43.

[2] *E.g.*, in above case by introducing into the galvanometer circuit $\frac{9}{10}$ths, $\frac{99}{100}$ths, $\frac{999}{1000}$ths, respectively of the resistance of the multiplier.

[3] This arrangement is that adopted by White of Glasgow in the galvanometers made by him after Sir Wm. Thomson's pattern.

by the rolling of the ship, its centre of gravity is carefully adjusted so as to be in the axis of suspension. The mirror is enclosed in a narrow cell which just allows it room to deflect to the required extent, and damps the oscillation so effectually that the instrument is "dead beat." In order to destroy the directive action of the earth, the inconvenience of which in a galvanometer for use on board ship is obvious, the case of this galvanometer is made of thick soft iron, which completely encloses the whole, leaving only a small window for the ingress and egress of the ray of light by means of which the motions of the mirror are read; a flat horse-shoe magnet placed on the top of the case still farther overpowers the earth's force and directs the mirror.

All these galvanometers may, of course, be wound double and used differentially. When this is the case, a small auxiliary compensating coil is often used to correct the inequality of the magnetic fields due to the two sets of windings. This auxiliary coil is usually mounted on a spindle in the axis of the main coil, and can be moved backwards and forwards till a current passing through it and one set of windings in one direction, and through the other set of windings in the other direction, does not sensibly deflect the mirror.

The astatic arrangement described above (p. 51, fig. 4) is often adopted. A galvanometer of this construction by Elliot Brothers is shown in fig. 6. It may be questioned, however, whether for ordinary purposes the additional sensibility thus gained compensates for the increased complexity and cost of the instrument.

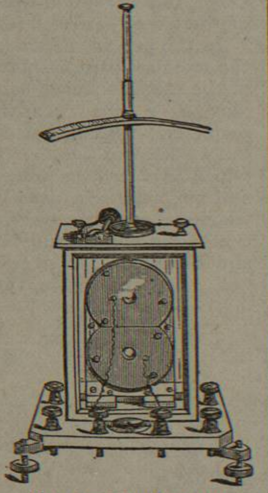

FIG. 6.—Elliot's Astatic Galvanometer.

Standard Galvanometers.—When galvanometers are intended for measuring currents, there must be some law connecting the indications of the needle with the strength of the current in the multiplier. It is therefore of great importance that slight variations in the position of the magnet should not introduce large or irregular (incalculable) variations into the indications of the instrument. Accordingly in standard instruments the windings are much farther removed from the magnet than in sensitive galvanometers, and in the best forms the multiplier is so disposed that it produces a uniform field of magnetic force around the needle.

The earliest forms of standard galvanometer were the tangent and sine compasses invented by Pouillet. The first of these consists simply of a single vertical coil of wire, with a magnet suspended at its centre, whose deflexion may be read in any of the various ways already described. If the length of the magnet be very small, the magnetic field in its neighbourhood may be regarded as uniform, and the electromagnetic couple will be proportional to cos θ, θ being the deflexion from the plane of the windings. If the windings be arranged so as to be in the magnetic meridian,[1] the couple due to the earth's action tending to bring the magnet back to its position of equilibrium will be proportional to sin θ, hence the current strength will be proportional to tan θ.

If the multiplier be movable about a vertical axis through angles which can be measured in any way, the instrument may be used as a sine compass. The current is applied and the multiplier turned round after the magnet until the axis of the latter is again parallel to the windings. The current strength is now clearly proportional to sin θ, where θ is the deflexion of the multiplier from the magnetic meridian. When the instrument is used in this way, the needle being always brought into the same position relative to the windings, the uniformity of the magnetic field is a matter of indifference, and there is no necessity for the needle to be short.

Gaugain attempted to improve the tangent galvanometer by suspending the magnet excentrically at a point in the axis of the coil distant from the centre by half the radius of the coil. This, however, is in reality the reverse of an improvement.[2]

A real advance, however, was made by Helmholtz, who placed two equal parallel and vertical coils, one on each side of the magnet, each at a distance from it equal to half the common radius. In fig. 19, at the end of his second volume, Maxwell gives a diagram of the lines of force due to two equal parallel circular circuits, from which it will be seen that the magnetic field at the centre of such an arrangement of currents is very approximately uniform. This approximation may be carried still farther by adding a third coil parallel to the two others, and equidistant from them. In some examples of Helmholtz's galvanometer the windings are arranged on a conical surface, so that the ratio of the radius of each to the distance of its plane from the centre of the magnet shall be 2 : 1. In reality this is unnecessary, provided the ratio of the depth and breadth of the usual rectangular channel be properly adjusted (see Maxwell, vol. ii. sec. 713). Fig. 7 represents a galvanometer of the kind described.

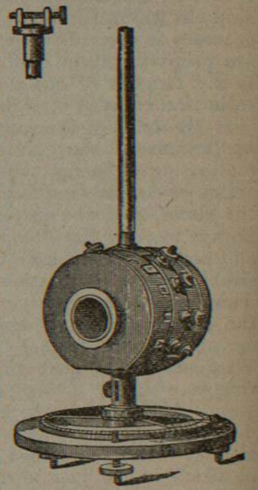

FIG. 7.—Galvanometer designed by Professor Maxwell.

The wire is wound in two parallel channels cut in a cylindrical block of hard wood, each an inch broad and an inch deep. The radius of the bottom of each channel is one inch, and the distance between them is half an inch. The cylindrical perforation in the core of the multiplier is $1\frac{3}{8}$ inch in diameter—large enough to allow the needle to swing freely without causing irregular air currents, &c. Into the ends of the core are screwed two caps containing a piece of plane parallel glass and a plano-convex lens respectively, the former for subjective, the latter for objective reading. By means of a slit and screw in the stem which supports the instrument, a horizontal bar can be fixed parallel to the axis of the multiplier. On this a deflecting magnet can be mounted, so that the galvanometer can be used as a magnetometer.

Reduction of Galvanometer Indications.—When the position of every layer of wire in the multiplier is known with sufficient accuracy, and the multiplier arranged so as to produce a sensibly uniform field, the electromagnetic action per unit of current can be calculated for every position of the magnet. In this case the galvanometer is an *absolute* instrument. When we possess one absolute instrument it is easy to evaluate the indications of any other in absolute measure by means of it; we have only to pass the same current through both galvanometers in series and compare the readings. The best way, however, to construct a standard galvanometer is to provide for uniformity of field in the core of the multiplier, and find the resultant electromagnetic force for unit current, or, as it is called, the constant of the instrument, by comparison with a pair of equal standard coils of large diameter (18 in. to 24 in.). These are arranged vertically on the same axis, the distance between them being equal to the mean radius, just as in Helmholtz's galvanometer. The galvanometer to be tested is placed symmetrically between the standard coils, the centre of its multiplier being near the centre of the whole arrangement, and the axes of all the coils coincident. A multiple arc is then formed, one branch of which contains the coils and the other the galvanometer, so that the magnetic actions oppose each other. The resistances of the two branches are then adjusted till the galvanometer needle gives no indication when a current is sent through the multiple arc. The whole arrangement will be understood from fig. 8. If R and S be the resistances in the branches containing the galvanometer and coils respectively, then the constant of the galvanometer is to that of the coils as R : S; so that when the latter is calculated[1] the former is known.

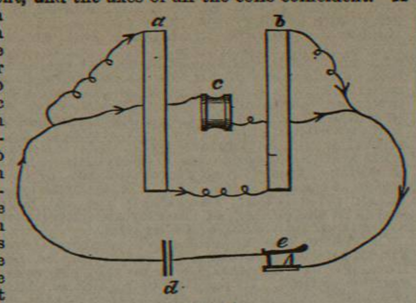

Fig. 8.

The constant of the galvanometer G being known, the value of a current producing a deflexion θ is given in absolute measure by

$$I=\frac{H}{G}\tan\theta,$$

H being the horizontal component of the earth's magnetic force.

In many cases it is necessary to correct for the torsion of the suspending fibre. The value of this correction is easily found by turning the multiplier[2] through 90° either way, and observing how far the needle follows it. The reader will find all necessary details in Maxwell, vol. ii., secs. 452, 742.

In all cases where great accuracy is required it is advisable to *graduate*, or, as it is sometimes said, to *calibrate* the galvanometer, that is, to compare the electromagnetic couple exerted by the multiplier when the needle is deflected through an angle θ with that when the needle is parallel to the windings. It is easy to see that this may be done by means of the arrangement described above for finding the constant of a galvanometer. If the object simply is to calibrate the galvanometer without reducing its indications to absolute measure, the standard coils may be replaced by a single coil of sufficient magnetic moment placed in the axis of the multiplier. Another method of calibration, which is simpler, and in some respects more satisfactory, although possibly more laborious, will be understood from fig. 9. The resistance *a* is equal to the resistance of the galvanometer, and they can be rapidly interchanged. By adjusting *f* the ratio of the currents in the branches of the multiple arc may be varied as we please, and by varying *e* the current in one of the branches can always be brought to a standard strength, say that which produces unit deflexion of the galvanometer needle. We can thus, by repeatedly interchanging *a* and *b*, compare the deflexions produced by a series of currents whose strengths are given multiples of the standard strength. If the experimenter has two galvanometers at his disposal the interchanges may of course be avoided.

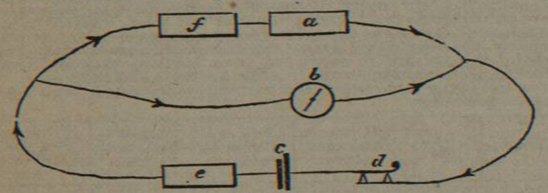

Fig. 9.

On the Use of the Galvanometer.—We may add a few remarks on the different uses to which a galvanometer may be put.

Detection of Currents.—One of the commonest of all the uses of a galvanometer is to indicate the currents sent through telegraph wires or cables. In the case of submarine cables, where the currents are often very feeble, dead-beat galvanometers of Thomson's or Varley's construction are used.

When a current is to be detected which produces a very small or quite insensible permanent deflexion, the following process, called the method of multiplication, is sometimes used. The period of oscillation of the needle is first found; then, the needle being at rest or only swinging through a very small arc, the current is applied through half the period of oscillation so as to urge the needle in the direction in which it is going, then intermitted for half a period, then applied again, and so on. If a current in the supposed direction really exist, the oscillations of the magnet will gradually increase, until the energy supplied by the intermittent action of the current is equal to that wasted by the damping of the needle.

It is obvious that this process is more effective the smaller the damping of the needle; it leads to no advantage whatever with a dead-beat instrument.

Resistance Measuring.—In comparing resistances, sensitive galvanometers of Sir William Thomson's construction[3] are by far the most convenient; the dead-beat arrangement is essential for rapid work.

If a differential galvanometer of given dimensions be used (see art. ELECTRICITY, p. 44), and if the resistance of the battery is negligible compared with the other resistances used, the wire with which it is wound should be chosen so that its resistance is one-third of the resistance to be measured.[4]

It is shown in the art. ELECTRICITY (p. 44) that, in arranging a Wheatstone's bridge to measure a given resistance, all the arms of the bridge and the battery and galvanometer should have equal resistances. As a rule, all these are not at our disposal. If the resistances of the arms and of the battery are given, and the resistance of the galvanometer (of given dimensions) is at our disposal, then the resistance of the galvanometer ought to be equal to that of the multiple arc which remains between the terminals of the galvanometer when the battery is disconnected from the bridge.[5] This may be deduced at once from the expression given in vol. viii. p. 44.

Again, the resistance to be measured and the battery and galvanometer resistance being given, we may inquire what is the best arrangement of the arms of the bridge.

Differentiating the expression given in vol. viii. p. 44 with respect to y and z, we get

$$BG-y^2z^2R^2=z\left\{y^2(R+G)R-G(R+B)\right\},$$
$$BG-y^2z^2R^2=y\left\{z^2(R+B)R-B(R+G)\right\};$$

the solution of which is obviously

$$y=\sqrt{\frac{G(R+B)}{R(R+G)}},\qquad z=\sqrt{\frac{B(R+G)}{R(R+B)}};$$

whence we have $S=\sqrt{RG\cdot\frac{R+B}{R+G}}$, $T=\sqrt{RB\cdot\frac{R+G}{R+B}}$, and $U=\sqrt{BG}$—determining the resistances of the disposable arms.

It appears that, when B and G are given, the resistance of the arm opposite to the resistance to be measured ought always to be the geometric mean between B and G.[6]

In a certain class of observations a needle with large moment of inertia is used. The methods in use are mostly due to Gauss and Weber. For an account of these methods the reader is referred to Maxwell, chap. xvi. He should also consult a paper by Du Bois Reymond in *Monatsber. d. Berl. Acad.*, 1869–70. (G. CH.)

GALVESTON.

GALVESTON, the largest and most extensively commercial city of the State of Texas, United States of America, is situated 340 miles west of the mouth of the South Pass of the Mississippi River, on Galveston Island, at the opening of the Bay of Galveston into the Gulf of Mexico. It is situated in latitude 29° 18′ north, and 94° 47′ west longitude. It is about two miles from the northeast corner of the island, which projection is known as Fort Point. It is a port of entry, and the principal seaport city of the State. Galveston is the county seat of Galveston county, of which the largest portion is on the main land, separated from the city and island by East and West Bays. The land is low and sandy and lies quite level. The island is long and narrow, extending parallel with the shore, in a northeasterly and southwesterly direction, for the distance of 28 miles, having an average width of about two miles.

Excellent opportunities are found for surf bathing on the beach, and for most beautiful drives during the periods of low tide. Bolivar Peninsula runs out from the main land to within two miles of Fort Point, and at the head of the peninsula is Bolivar Point lighthouse. The Galveston harbor is the best on the coast line of Texas. It has more than twelve and three-fourths feet of water over the bar at low tide. This bar stretches across the entrance to the bay and has been formed and maintained by the sand moved by the constant undertow of waves and currents.

Trinity River flows into the northern end of the bay, and San Jacinto River and Buffalo Bayou empty into it a little further south. The mean rise and fall of the tide is a little over one foot, but spring tides rise as high as three feet above

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[1] This can be done most easily by means of a mirror attached to the multiplier and adjusted so as to be parallel to the windings.

See Maxwell, *Electricity and Magnetism*, vol. ii. secs. 712, 713.

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[1] See for such calculations Maxwell, vol. ii., chaps. xiv. and xv.

[2] Or the piece to which the fibre is attached, if it is not rigidly attached to the multiplier.

and fall two feet below the mean low-water mark. Under the influence of heavy winds and storms, the rise has been as high as nine feet.

The harbor at Galveston, having a depth at its entrance at the present time of nearly fourteen feet, is the best harbor on the entire gulf coast from the mouth of the Mississippi to the Rio Grande. It is also believed to be the one most susceptible of such improvements as would constitute a harbor of the first class. Its superiority to the other ports of Texas is clearly indicated by the coast survey charts and by the fact that the principal railroads of this State extend to Galveston or connect with railroads terminating at that point. The value of railroad properties in the State of Texas is about one hundred and sixty millions of dollars. This large expenditure of private capital in supplying means of internal transportation in Texas, expresses faith in the resources of this State, and emphasizes the importance of securing for it a first-class seaport. Such expenditure stands also as the strongest indorsement of any practical plan for the accomplishment of that object. The proposed improvement of the entrance to the port of Galveston would constitute a connecting link between this great system of internal transportation and the ocean, nature's great free highway of commerce. If the proposed depth of thirty feet at the entrance to the port of Galveston can be secured, that port would become the nearest and most accessible first-class seaport for the States of Texas, Kansas, New Mexico and Colorado, the Indian Territory and the Territory of Arizona, and parts of the States and Territories adjoining those just mentioned. The central portions of the State of Kansas are about equidistant from Chicago and Galveston. If the harbor of Galveston shall be so improved as to admit the entrance of vessels of the largest size, the various railroads connecting this city with Arkansas, Western Missouri, Western Iowa, Kansas, Nebraska, Colorado, and New Mexico, will become active competitors with the railroads extending east, not only with respect to trade with Europe, but also with respect to the trade between the area referred to and the chief Atlantic seaports.

The coast line of Texas from Sabine Pass to the Rio Grande, measures about 375 statute miles. In this distance there are four points which are now receiving the attention of the government with a view to harbor improvement, viz: Sabine Pass at the eastern extremity of the line; Brazos Santiago at the western extremity; Galveston, 65 miles from the eastern extremity, and Aransas Pass, 138 miles from the western extremity. The area of water in the Galveston harbor, 24 feet deep, is 1,304 acres, 30 feet deep, 463 acres, and a considerable acreage of 40 and 50 feet depth.

It is thus seen that the natural advantages which created Galveston and made her the principal port of the State still exist to maintain her pre-eminence.

The old south jetty has been built up to a height of five feet above mean low tide to a distance of 4,550 feet seaward, and connected with the shore by a wall of ordinary riprap 1,100 feet long, sloping gradually downward to the level of the ground, which is about six inches above mean low tide. The work of extending the jetty seaward was continued until July 17, 1888, when it was suspended for lack of funds. Additional funds having been provided in the River and Harbor act of August 11, 1888, work was resumed October 15, 1888, under a new contract, dated October 13, 1888. During the year a shore branch 8,464 feet long was constructed to connect the former work with the relatively high ground upon which Galveston is built. The object of this work is twofold, viz: to furnish a secure anchorage point for the south jetty, and also to improve the Galveston channel. The total length of the railway upon the crest of the jetty, including that built upon the trestle in advance of the stonework, is 17,375 feet. The level of mean low tide was five inches higher for the year 1888 than the level fixed for that plane in 1872.

The number of steam vessels entered at the port of Galveston for the year ending June 30th, 1887, was 250; number of sail vessels entered was 296. Total number of vessels 546. The tonnage of all vessels was 446,711 tons. The total value of their cargo was $27,903,000, and they carried 3,000 passengers. The number of steam vessels cleared was 256. The number of sail vessels cleared was 238. Total number of vessels, 494.

The tonnage of vessels cleared was 444,801 tons, valued at $73,874,701. The majority of vessels draw fifteen to twenty feet of water when fully loaded.

In addition to these there is a large number of small schooners, drawing five feet or less, engaged in the coasting trade.

The first settlement of Galveston was made in 1837. From 1817 to 1821 it had been the haunt of the famous pirate Lafitte, who was finally dislodged from the island in the latter year. The city is handsomely laid out upon ground which lies very even, elevated six or eight feet above the sea level. Its streets are straight, broad, and elegant; those running parallel with the bay are designated as avenues, and those at right angles simply as streets. The avenues are called by the letters of the alphabet, beginning on the bay front, and the streets are numbered First, Second, etc. The public building, containing the post-office and United States court house, stands at the crossing of 20th street and avenue "F." The avenues between this building and the bay are devoted to shipping and wholesale business, retail stores, shops, restaurants, hotels, banks and offices. Broadway, or avenue "J," is the most beautiful residence avenue of Galveston, and is considered the St. Charles of the city. Like some other southern cities, Galveston has been laid out upon a generous plan. Avenue "J" is 150 feet wide. An esplanade 36 feet in width runs through the middle, and its sidewalks are 16 feet wide on either side. The next street in point of width is Bath street, which is 120 feet wide. All the other streets are 80 feet wide and the avenues are 70 feet wide; all have sidewalks 16 feet in width. A shell road runs from the bay to the beach, which is called Fremont street. It is a favorite resort, as well as the beach, for driving. The streets are not paved, though the sidewalks in the center of the city are paved either with concrete or asphalt, or laid with brick or tile.

Galveston has a number of churches and schools of various kinds, an opera house and seven public halls. There are two libraries, two theaters, three market places and fourteen hotels of various grades. In the line of public buildings Galveston has a postoffice, custom house, and United States court house, a county court house, a county and city prison and a city hall. The churches number 15, and the schools, of all kinds, 30. It is also the see of the Bishop of the Roman Catholic Church for that diocese. Galveston has several foundries, flour and planing mills and machine shops. The wharves are good, and there are several ship-building yards, and cotton-presses. Papers, daily and weekly, as well as bi-weekly and tri-weekly, are published. There are two railroad bridges across West Bay—one two miles long—connecting the island with the main land, but no highway bridges have as yet been built. Cotton and cotton-seed oil form the great bulk of the foreign exports, which exceeded $17,000,000 in 1887. The foreign imports for the same year reached $1,765,612.

The following is a statement for 1878, 1879 and 1880 of the receipts from duties on imports and other sources, such as "tonnage tax," "hospital tax," etc.

From—	Imports.	Other Sources.
Jan. 1, 1878, to Dec. 31, 1878	$43,006 51	$23,035 97
Jan. 1, 1879, to Dec. 31, 1879	128,543 51	26,982 46
Jan. 1, 1880, to Feb. 13, 1880	24,196 65	2,433 15
Probable amount of collections during the year ending Dec. 31, 1880, approximated from invoices on hand and other reliable data		$250,000 00

The value of imports from foreign countries for the years 1877 and 1878 was $1,357,488 and $1,357,488 respectively. These imports consist mainly of coffee, woolen and cotton goods, and iron goods.

Galveston has railway communications with all parts of the country, and by lines of steamships with Liverpool, New York, New Orleans, and the ports of Texas as far as the Mexican boundary. These vessels engage to a large extent in direct trade with Great Britain and the continent of Europe, in the coffee trade with Rio Janeiro, and in the West Indies and Mexican trade. There are six cotton presses, with warehouses and yards occupying more than 40 acres of ground and storing more than 100,000 bales of cotton. There are ten miles of street railroads in the city; one savings bank and national banks with a capital of more than $800,000, and a paid up capital of $300,000. Galveston's taxable values were $21,000,000 in 1889. Galveston has not been visited by any epidemic disease since the yellow fever scourge of 1867. In other respects it is considered a most healthful city, possessing a delightful climate, and in every way is an inviting city to live in, affording abundant opportunities for business and pleasure.

The following table shows the rainfall, temperature and barometric pressure:

Year.	Rain Fall.	Highest Temperature.	Lowest Temperature.	Mean Temperature.	Mean Bar. Pressure.
1875	46.66 in.	98.5°	24°	69.6°	30.063 in.
1876	70.59	97°	40°	70.9°	30.050 "
1877	42.99	96°	30°	68.7°	30.073 "
1878	67.47	97°	30°	70.2°	29.997 "

The population for 1850 was 4,177. In the next ten years it nearly doubled, so that the census for 1860 shows a population of 7,307; for 1870, 13,818; for 1880, 24,121.

Galveston is, without a doubt, destined to become one of the most important shipping ports of the United States. It is connected with the great railroad lines running into the interior and Northwest, and under proper management will afford a cheaper outlet for that great country than the overland railroad route. The great demand now is for improved harbor facilities. The people of Texas and Galveston recognize this demand, and at their earnest instigation the government is taking hold of the matter with vigor. An improved harbor is all that is required. Nature has done all that is possible to be done in furnishing shelter and protection and abundance of space. The competition that an excellent harbor would encourage, would build up still more rapidly this already fast growing city of our Southwest.

This competition would assert itself not only in the transportation of the products of the interior by way of Galveston, but also, and perhaps to a greater extent and more beneficially, in the regulating influence which it would exert over the rates charged by all the east and west railroads extending from Chicago to the Atlantic seaboard. The magnitude of the advantages which would be thus afforded to the commercial and industrial interests of the country, it is impossible accurately to compute or even approximately estimate, but the great importance of such advantages is clearly apparent. In view of the vast area of country, the commercial and industrial interests of which would be directly subserved by the proposed improvement in the harbor of Galveston, and by the fact that such improvement would also, through competition, directly benefit a very large proportion of the whole country, it appears proper to characterize that project as a work of great national importance.

About $1,500,000 were wasted by the government prior to the year 1886, in some tentative engineering experiments. The present plans and estimates were adopted in 1886, at which time Major O. H. Ernst was first assigned in charge of the work. Under his management the channel depth upon the outer bar was found to be 13¼ feet and that upon the inner bar 21 feet, both at mean low tide, which was in both cases an increase of 6 inches during the year 1888. The distance across the outer bar from 24 feet inside to 24 feet outside has diminished from 14,100 to 13,500 feet, a difference of 600 feet or about 4 per cent. The distance from 18 feet inside to 18 feet outside has diminished from 7,180 feet to 6,340 feet, a difference of 840 feet or nearly 12 per cent. The old mattress jetty, built previous to the year 1886, has continued to deteriorate. The average depth over the outer 5,000 feet of it was ten feet.

Of this work Captain Eads says: "A less channel than thirty feet should not be contemplated, inasmuch as cheap freights require vessels of deep draft, and there is no reason why such works should not be constructed at Galveston as would place her harbor within the reach of the largest carriers now contemplated. At least twenty feet could be relied on within two years after the work is begun, and about two or three feet each year thereafter until the thirty feet is obtained. The deepening would continue slowly under tidal action for several years thereafter, and I should expect it to reach at least thirty-five or possibly forty feet before a permanent regimen would be established through the channel. I have estimated the necessary works at Galveston to secure a permanent channel thirty feet deep at seven and three-quarters millions of dollars."

Why the government is directing its attention to Galveston and Galveston harbor instead of the other ports of Texas may be readily understood from the government estimates made in 1886.

The channel depth over the bar at that time was:

Sabine Pass	8 feet
Galveston	12¾ feet
Aransas	8½ feet
Brazos Santiago	5 feet

—all measured at mean low tide. Foreign vessels which now visit the Texas coast draw about twenty feet, and to accommodate them there should not be less than twenty feet depth of channel over the bar. It can be obtained by suitable improvements at Sabine, Galveston, and Aransas, but not at Brazos Santiago. For safe anchorage, these vessels require about twenty-four feet in the harbor. The area of water twenty-four feet deep is, at

Sabine	100 acres
Galveston	1,304 acres
Aransas	60 acres

The improvements designed to furnish twenty feet depth over the bar at these places have been begun. To complete them there remains to be appropriated, for

Sabine	$2,379,000 00
Galveston	2,200,000 00
Aransas	1,471,000 00

Dividing these numbers by the number of acres of deep water, we find the cost per acre to reach the anchorage is, for

Sabine	$23,790 00
Galveston	1,687 11
Aransas	24,516 17

The depth of twenty feet over the bar, which is sufficient to answer the most immediate pressing needs of Texas, is not sufficient to admit many large commercial vessels and ships of war. To accommodate these an extension of the improvements at Galveston is contemplated, designed to give a depth of thirty feet at a cost of four millions additional to the amount mentioned above. No thirty-foot channel over the bar has been projected at either of the other places. The area of water thirty feet deep is, at

Sabine	63 acres
Galveston	463 acres
Aransas	19 acres

The vast country, that presents a front to the sea of three hundred and twenty-six miles, and of which Galveston is the only outlet that can be utilized for the accommodation of large vessels, as the certificates of experienced men who have been engaged in the coasting trade for years will evidence, demands from the general government some recognition of its importance to the commerce of the world. The resources of the State are but partially developed. Its population and productions are increasing with each succeeding year, and the time must inevitably come when Texas will assume grander proportions in all the essentials that can contribute to the prosperity of mankind. Its climate is salubrious and is blended with all the blessings and benefits that can be bestowed by fertile lands.

GALWAY, a maritime county in the province of Connaught, in the extreme west of Ireland, between 52° 54′ and 53° 43′ N. lat., and 7° 57′ and 10° 20′ W. long. It is bounded on the N. by Mayo and Roscommon; E. by Roscommon, King's County, and Tipperary; S. by Clare and the Bay of Galway; and W. by the Atlantic Ocean. The area comprises 2447 square miles. or 1,566,354 acres, of which 90,230 are under water.

Surface.—The county is naturally divided by Lough Corrib into two great divisions. The eastern, which comprehends all the county except the four western baronies, rests on a limestone base, and is, generally speaking, a level champaign country, but contains large quantities of wet bog Its southern portion is partly a continuation of the Golden Vale of Limerick, so celebrated for its fertility, and partly occupied by the Slievebaughty Mountains. The northern portion of the division contains rich pasture and tillage ground, beautifully diversified with hill and dale. Some of the intermediate country is comparatively uncultivated, but forms excellent pasturage for sheep. The western division of the county has a substratum of granite, and is barren, rugged, and mountainous. It is divided into the three districts of Connemara, Jar-Connaught, and Joyce's Country; the name of Connemara is, however, often applied to the whole district. Its highest mountains are the grand and picturesque group of Binabola, or the Twelve Pins, which occupy a space of about 25 square miles, the highest elevation being about 2400 feet. Much of this district is a gently sloping plain, from 100 to 300 feet above sea-level. Joyce's Country, further north, is an elevated tract, with flat-topped hills of from 1300 to 2000 feet high, and deep narrow valleys lying between them.

Coast.—Galway enjoys the advantage of a very extended line of sea-coast, indented by numerous harbours, which, however, are rarely used except by a few coasting and fishing vessels. Commencing at the coast of Mayo in the north are the Killeries, two bays which separate the counties of Galway and Mayo. The first bay on the western coast capable of accommodating large ships is Ballynakill, sheltered by Freaghillaun or Heath Island. Next in succession is Cleggan Bay, having Inishboffin in its offing. Streamstown is a narrow inlet, within which are the inhabited islands of Omey, Turbot, and Inishturk. Ardbear harbour divides itself into two inlets, the northern terminated by the town of Clifden, with excellent anchorage opposite the castle; the southern inlet has also good anchorage within the bar, and has a good salmon-fishery. Mannin Bay, though large, is much exposed, and but little frequented by shipping. From Slyne Head the coast turns eastward to Roundstone Bay, which has its entrance protected by the islands of Inishnee and Inishlacken. Next in order is Birterbuy Bay, studded with islets and rocks, but deep and sheltered. Kilkerrin Bay, the largest on this coast, has a most productive kelp shore of nearly 100 miles; its mouth is but 8 miles broad. Between Gorumna Island and the mainland is Greatman's Bay; and close to it Costello Bay, the most eastern of those in Connemara. The whole of the coast from Greatman's Bay eastward is comprehended in the Bay of Galway, the entrance of which is protected by the three limestone islands of Aran—Inishmore (or Aranmore), Inishmann, and Inisheer.

Rivers.—The rivers are few, and, except the Shannon, are of small extent. The Suck, which forms the eastern boundary of the county, rises in Roscommon, and passing by Ballinasloe, unites with the Shannon at Shannon bridge. The Shannon, which rises at the foot of Cuilcagh in the county of Cavan, forms the south-eastern boundary of the county, and passing Shannon Harbour, Banagher, Meelick, and Portumna, swells into the great expanse of water called Lough Derg, which skirts the county as far as the village of Mount Shannon. The Claregalway flows southward through the centre of the county, and enters Lough Corrib some 4 miles above the town of Galway. The Ballynahinch, considered one of the best salmon-fishing rivers in Connaught, rises in the Twelve Pins, passes through Ballynahinch Lake, and after a short but rapid course falls into Birturbuy Bay.

Lakes.—The Lakes are numerous. Lough Corrib extends from Galway town northwards over 30,000 acres, with a coast of 56 miles in extent. It has now been made navigable to Lough Mask (which lies chiefly in Mayo county) and to the sea at Galway. The lake is studded with many islands, some of them thickly inhabited. Near it is Lough Ross, which receives a large supply of water from streams, but has no visible outlet. The district to the west of Lough Corrib contains in all about 130 lakes, about 25 of them more than a mile in length. Lough Rea, at the town of the same name, is more remarkable for scenic beauty than for extent. Besides these perennial lakes, there are several low tracts, called turloughs, which are covered with water during a great part of the year.

Geology and Minerals.—The boundary line between the limestone and granitic district is easily discernible by the diminution of the verdant hue which distinguishes the latter. The high road from Galway to Oughterard nearly marks the division. All the country to the north and east of this limit is limestone, all to the south and west granite, excepting some detached masses of primitive limestone between Oughterard and Clifden, and some scattered portions of