fixed in the centre, as shown at C, fig. 6. The cable is carefully coiled into the tanks in horizontal flakes, each of which is begun at the outside of the tank and coiled towards the centre. The different

coils are prevented from adhering by a coat­ing of whitewash, and the end of each nautical mile is carefully marked for future reference. After the cable has been again subjected to the proper electrical tests and found to be in perfect condition, the ship is taken to the place where the shore end is to be landed. A sufficient length of cable to reach the shore or the cable-house is paid overboard and coiled on a raft or rafts, or on the deck of a steam-launch, in order to be connected with the shore. The end is taken into the testing room in the cable-house and the conductor connected with the testing instruments, and, should the electrical tests continue satis­factory, the ship is put on the proper course and steams slowly ahead, paying out the cable over her stern. The cable must not be over­strained in the process of submersion, and must be paid out at the proper rate to give the requisite slack. This involves the intro­duction of machinery for measuring and controlling the speed at which it leaves the ship and for measuring the pull on the cable. The essential parts of this apparatus are shown in fig. 6. The lower end *e* of the cable in the tank T is taken to the testing room, so that continuous tests for electrical condition can be made. The upper end is passed over a guiding quadrant Q to a set of wheels or fixed quadrants 1, 2, 3,... then to the paying-out drum P, from it to the dynamometer D, and finally to the stern pulley, over which it passes into the sea. The wheels 1, 2, 3, ... are so arranged that 2, 4, 6, ... can be raised or lowered so as to give the cable less or more bend as it passes between them, while 1, 3, 5,... are furnished with brakes. The whole system provides the means of giving sufficient back-pull to the cable to make it grip the drum P, round which it passes several times to prevent slipping. On the same shaft with P is fixed a brake-wheel furnished with a powerful brake B, by the proper manipulation of which the speed of paying out is regulated, the pull on the cable being at the same time observed by means of D. The shaft of P can be readily put in gear with a powerful engine for the purpose of hauling back the cable should it be found necessary to do so. The length paid out and the rate of paying out are obtained approximately from the number of turns made by the drum P and its rate of turning. This is checked by the mile marks, the known position of the joints, &c., as they pass. The speed of the ship can be roughly estimated from the speed of the engines ; it is more accurately obtained by one or other of the various forms of log, or it may be measured by paying out continuously a steel wire over a measuring wheel. The average speed is obtained very accurately from solar and stellar observations for the position of the ship. The difference between the speed of the ship and the rate of paying out gives the amount of slack. The amount of slack varies in different cases between three and ten per cent., but some is always allowed, so that the cable may easily adapt itself to inequalities of the bottom and may be more readily lifted for repairs. But the mere paying out of sufficient slack is not a guarantee that the cable will always lie closely along the bottom or be free from spans. Whilst it is being paid out the portion between the surface of the water and the bottom of the sea lies along a straight line, the component of the weight at right angles to its length being supported by the frictional resistance to sinking in the water. If, then, the speed of the ship be *v,* the rate of paying out *u,* the angle of immersion, *i,* the depth of the water *h,* the weight per unit length of the cable *w,* the pull on the cable at the surface P, and A, B constants, we have—

P*=h*{*w-*A/sin*i* (*f*)(*u*-*v*cos*i*)} (*a*)

and *w*cos*i*=B*f*(*v*sin*i*)*.....................................*(β),

where *f* stands for “ function.” The factors A*f* (*u-υ* cos *i*) and B*f* (*υ* sin *i*) give the frictional resistance to sinking, per unit length of the cable, in the direction of the length and transverse to the length respectively.@@1 It is evident from equation *(β)* that the angle of immersion depends solely on the speed of the ship ; hence in laying a cable on an irregular bottom it is of great im­portance that the speed should be sufficiently low. This may be illustrated very simply as follows :—suppose *a a* (fig. 7) to be the surface of the sea, *bc* the bottom, and *cc* the straight line made by the cable ; then, if a hill H, which is at any part steeper than the inclination of the cable, is passed over, the cable touches it at some point *t* before it touches the part immediately below *t,* and if

the friction between the cable and the ground is sufficient the cable will either break or be left in a long span ready to break at some future time. It is important to observe that the risk is in no way obviated by the increasing slack paid out, except in so far as the amount of sliding which the strength of the cable is able to produce at the points of contact with the ground may be thereby increased. The speed of the ship must therefore be so regulated that the angle of immersion is as great as the inclination of the steepest slope passed over. Under ordinary circumstances the angle of immersion *i* varies between six and nine degrees.@@2

*Qualities of a Telegraph Line.—*The efficiency of the telegraph depends on three qualities of the main line—(1) its conducting quality, (2) its insulation, and (3) its electrostatic capacity.

1. The conducting quality of a wire or other elongated portion of matter is measured by the quantity of electricity which it allows to flow through it when a stated “electromotive force,” or “ difference of electric potentials,” is maintained between its two ends. It may be most naturally, and is in point of fact generally, expressed in terms of resistance to transmission, regarded as a quality inverse to that of conducting power, and expressed numerically by the reci­procal of the measure of the conducting power. An independent explanation and definition of the electrical resistance of a conductor may be given as follows :—the electrical resistance of a conductor is measured by the amount of electromotive force, or difference of potentials, which must be maintained between its ends to produce a stated strength of electric current through it.
2. The true measure of the insulation of a body is the resistance to conduction offered by its supports. The reciprocal of this, or the conducting power of the supports, measures the defectiveness of the insulation. Since no substance yet known is absolutely a non­conductor of electricity, perfect insulation is impossible. If, however, the supports on which a telegraph wire rests present, on each part and on the whole, so great a resistance to electric conduc­tion as to allow only a small portion of the electricity sent in, in the actual working, at one end to escape by lateral conduction, instead of passing through the line and producing effect at the other end, the insulation is as good as need be for the mode of working adopted. With the good insulation attained in a submarine line, round every part of which the gutta percha is free from flaws, no telegraphic operation completed within a second of time can be sensibly influenced by lateral conduction. A charge communicated to a wire thus insulated under water, at the temperature of the sea- bottom, is so well held that, after thirty minutes, not so much as half of it is found to have escaped. From this, according to the familiar “compound interest” problem, it appears that the loss must be at the rate of less than five per cent. per two minutes.
3. In 1849 Werner Siemens proved that “when a current is sent through a submerged cable a quantity of electricity is retained in charge along the whole surface, being distributed in proportion to the tension of each point,”—that is to say, to the difference of potentials between the conductor at any point and the earth beside it. In 1854 Faraday showed the effect of this “electrostatic charge” on signals sent through great lengths of submerged wire, bringing to light many remarkable phenomena and pointing out the “inductive” embarrassment to be expected in working long sub­marine telegraphs. In letters@@3 to Professor Stokes in November and December of the same year, Prof. W. Thomson gave the mathe­matical theory of these phenomena, with formulæ and diagrams of curves, containing the elements of synthetical investigation for every possible case of practical operations. Some of the results of this theory are given at the end of the present article. The con­ductor of a submarine cable has a very large electrostatic capacity in comparison with that of a land telegraph wire in consequence of the induction, as of a Leyden phial, which takes place across its gutta percha coat, between it and its moist outer surface, which may be regarded as perfectly connected with the earth,—that is to say, at the same potential as the earth. The mathematical expres­sions for the absolute electrostatic capacity C, per unit of length, in the two cases are as follows.

Let D=diameter of the inner conductor, supposed to be that of a circular cross section, or of a circle inappreciably less than one cir­cumscribed about the strand which constitutes a modem submarine

@@@1 See Sir W. Thomson, *Mathematical and Physical Papers,* vol. ii. p. 165.

@@@2 For details of cable manufacture and laying consult Douglas’s *Telegraph Construction,* London, 1877, and Captain V. Hoskiær’s *Laying and Repairing of Electric Telegraph Cables,* London, 1878.

@@@3 Published in *Proc. Roy. Soc.* for 1855.