ROUTLEDGE'S
POPULAR SCIENCE
LIBRARY

The
Electric
Telegraph

Bernard Fitch
Smithsonian Inst

APR 11
3.

THE TELEGRAPH

THE TELEGRAPH

TRANSLATED FROM THE FRENCH OF

A.-L. TERNANT

BY

R. ROUTLEDGE, B.Sc., F.C.S.

WITH 196 ILLUSTRATIONS

LONDON

GEORGE ROUTLEDGE AND SONS, LIMITED

BROADWAY, LUDGATE HILL

MANCHESTER AND NEW YORK

1895

LONDON:

BRADBURY, AGNEW, & CO. LD., PRINTERS, WHITEFRIARS.

CONTENTS.

INTRODUCTION 1 to 3

The three main problems of the telegraph, 1—The agents employed in telegraphy, 2—Electricity the most effective agent, 3.

PART I.

OPTICAL TELEGRAPHY—ACOUSTIC TELEGRAPHY—PNEUMATIC TELEGRAPHY.

CHAPTER I.

OPTICAL TELEGRAPHY 4 to 23

System of the Ancients, 4—Various methods before Chappe's telegraph, 5—Visual telegraph of Chappe and his brothers, 7—Chappe's telegraph adopted in 1793 by France, 9—Visual telegraphy used in the Crimean War, and subsequently, 12—Mangin's optical telegraph for military purposes, 13—Leseurre's heliographic apparatus, 17—Mance's heliograph, 21—Thompson's system of distinguishing lighthouses, 22.

CHAPTER II.

ACOUSTIC TELEGRAPHY 24 to 49

Ancient systems, 24—Speaking tubes, 25—String telegraph, 26—Telephones, 28—Telephone companies, 31—Gower's telephone, 32—Telephone exchanges, 35—The apparatus and mode of working, 39.

CHAPTER III.

PNEUMATIC TELEGRAPHY 50 to 77

History, 50—Arrangement of the tubes in London, 51—Carriers, 53—Varley's valves, 54—Apparatus and engines for condensing and

exhausting air, 59—Motion of the carriers, 64—Signals, 66—Derangements, 68—Mode of finding the position of an obstruction, 69—Various accidents, 71—Continuance of the service during derangements, 72—The system of lines in Paris, 73—The system in Berlin, 76—The compressed air telegraph, 77.

PART II.

THE ELECTRIC TELEGRAPH.

CHAPTER I.

HISTORY 78 to 105

First attempts, 78—Scemmering, 79—Schilling, 80—Ampère, 82—Cooke, 83—Wheatstone, 84—Morse, 88—The first electric telegraph in England, 90—In other countries, 91—In France, 92—In 1840, a submarine telegraph suggested by Wheatstone, 95—Walker's experiments at Folkestone, 96—Brett's submarine cables, 98—Cable laid between England and France, 101—A second cable laid, 103.

CHAPTER II.

CONSTRUCTION OF LAND LINES OF TELEGRAPH . . . 106 to 143

The wires, 106—Joining the wires, 108—Posts, 109—Iron posts, 110—Insulating supports of various kinds, 114—Stretchers or strainers, 123—Construction of the line, 127—Fixing the posts, 132—Placing the wires, 135—Aërial lines in English towns, 135—Subterranean lines, 137—Fixing the wires in tunnels and to walls, 142.

CHAPTER III.

MAKING AND LAYING SUBMARINE CABLES . . . 144 to 193

Progress of submarine telegraphy, 144—The electrical and mechanical conditions required in a cable, 146—Process of manufacture, 147—India-rubber and gutta-percha, 152—The core of the cable, 154—The protective covering, 155—The strength of cables, 156—The storage of cables, 158—Paying out the cable at sea, 160—The paying-out

machinery, 163—Brakes and dynamometer, 164—Choice of route, 166—Laying shore cables, 168—Causes of accidents to cables, 170—Physical causes, 170—Destructive animals, 173—Accidental mechanical causes, 177—Repairs to cables, 178—Taking up machinery, 179—Appliances for grappling and buoying cables, 180—Methods of repairing cables, 183—Process of recovering the Atlantic cable from deep water, 186.

CHAPTER IV.

SOURCES OF ELECTRICITY 194 to 210

Voltaic batteries, 194—Daniell's, Siemens', 195—Minotto's, 198—Thomson's, 199—Callaud's, 201—Grove's, 203—Leclanché's, 204—English common battery—Magnetic properties of a wire connecting the poles of a battery, 206—Electrical resistance, 207—Various methods of connecting the cells of a battery, 208—The multiplier or galvanometer, 209—Electro-magnets, 210.

CHAPTER V.

TELEGRAPHIC APPARATUS 211 to 263

The single-needle instrument, 211—Various forms of manipulators or transmitting keys, 214—The mirror galvanometer, 215—The distributor, 216—The condenser, 218—Thomson's siphon recorder, 221—Adjustments: Of the paper, 222—Of the siphon and signal coil, 223—Of the electrical mill, 224—Smith's commutator, 225—Morse's apparatus, 228—Relays, 230—Siemens' polarized relay, 232—Morse key, 234—English post-office key, 235—Wheatstone's automatic apparatus, 237—Mode of connecting up the whole telegraphic apparatus at a terminal station, 244—Hughes' printing telegraph, 246—The "sounder," 250—Duplex telegraphy, 251—Duplex telegraphy with submarine cables, 256—The artificial line, 257—Accessory apparatus, 260—Earth plates, 260—Lightning conductors, 261.

CHAPTER VI.

POSITION OF FAULTS 264 to 270

Derangements, 264—Causes of faults, 264—Instrumental tests, 265—Calculation of the position of a fault, 267.

CHAPTER VII.

VARIOUS APPLICATIONS OF TELEGRAPHY . . . 271 to 289

Use of the telegraph on railways, 271—Railway signals in France, 272
—Telegraphy for fire alarms, 275—Military telegraphs, 278—Applica-
tion to meteorology, 286—Other applications, 287.

LIST OF ILLUSTRATIONS.

Fig.		Page
1	Chappe's Telegraph	8
2	Signal Towers	11
3	Mangin's Military Telegraph (section)	14
4	Mangin's Military Telegraph	15
5	Leseurre's Heliograph	18
5a	Leseurre's Heliograph (the screens)	19
6	Mance's Heliograph	20
7	Telegraphic Communication	29
8	Gower's Telephone	33
9	Telephone Signalling Apparatus	35
10	Telephone Signalling Apparatus (diagram)	37
11	Box of Telephone Signals	38
12	Telephone Commutator	39
13	Telephone Exchange	41
14	Telephone Exchange	43
15	Telephone Switchman	44
16	Office Telephone	45
17	Telephone Employé Receiving a Call	46
18	Despatch Carrier	53
19	Varley's Valves	54
20	Varley's Valves	55
21	Varley's Valves	56
22	Wilmot's Valve	57
23	Wilmot's Valve	57
24	Siemens' System of Tubes	61
25	Diagram of Circuits	62
26	Wells for Condensed Water	63
27	Receiving and Transmitting Valves	64
28	Receiving and Transmitting Valves	65
29	Receiving and Transmitting Valves	66
30	Receiving and Transmitting Valves	67

Fig.		Page
31	Signals for Pneumatic Tubes	69
32	Apparatus for Finding Position of Stopped Carrier	70
33a	Machinery for Pneumatic Tubes	73
33b	Machinery for Pneumatic Tubes	75
34	Walcker's Compressed Air Bell	77
35	Experiments at Folkestone	97
36	Vertebrated Shore Cable	99
37	Vertebrated Shore Cable (stronger)	99
38	Brett's Protected Cable	100
39	Laying the Channel Cable	103
40	The Channel Cable when Taken up	104
41	Pulleys for Winding Wires	107
42	Tools for Joining Wires	108
43	Joining of Wires	108
44	Joining of Wires	109
45	Iron Posts	111
46	Mode of Fixing Iron Posts	112
47	Siemens' Posts	113
48	Oppenheimer's Posts	115
49	Oppenheimer's Posts	115
50	Lee and Rogers' Iron Posts	116
51	Insulators	117
52	Insulators	117
53	Insulators	119
54	Insulators	119
55	Insulators (supports)	119
56	Insulators	120
57	Insulators	120
58	Insulators and Supports	121
59	Insulators and Supports	122
60	Insulators and Supports	122
61	Insulators and Supports	123
62	Insulators and Supports	123
63	Insulators (Attachments)	124
64	Insulators (Attachments)	124
65	Insulators (Attachments)	125
66	Stretcher	125
67	Stretchers	126
68	Stretchers	126
69	Stretchers	126

Fig.		Page
70	Lines Crossing a Road	128
71	Posts in Sharp Curves	130
72	Coupled Posts	130
73	Stayed Posts	131
74	Holes for Posts	132
75	The Spanish Ladle	133
76	Marshall's Boring Apparatus	133
77	Marshall's Boring Apparatus	134
78	Insulators in Towns	137
79	Insulators in Towns	137
80	Troughs for Underground Lines	139
81	Filling of Slits in Flanges	140
82	Filling of Slits in Flanges	140
83	Enlargements for Examination	140
84	Mode of Attaching Wires to Walls	141
85	Section of Cable	142
86	Brackets for Fixing into Walls	142
87	Portrait of Sir J. Pender	144
88	Portrait of Baron d'Erlanger	145
89	Portrait of Sir J. Anderson	146
90	Portrait of Sir D. Gooch	147
91	Machinery for Manufacturing Cables	149
92	Machinery for Manufacturing Cables	150
93	Splicing a Cable	151
94	Cable between Marseilles and Algeria	153
95	Machine for Covering Core	154
96	Cable between Cagliari and Bône	155
97	Machine for Covering Cables	156
98	Machine for Covering Cables	157
99	Section of Shore Cable	158
100	Cable with Protected Iron Wires	159
101	Cable with Muntz Metal Sheath	159
102	Storage of a Cable at Works and on Steamer	161
103	Section of Ship with Cable, &c.	162
104	Paying-out Machinery	163
105	The Appold Brake	165
106	Landing Shore End of Cable	166
107	Landing End of Cable, 1865, with Boats	167
108	Landing End of Cable, 1866, with Boats	168
109	Landing End of Cable by Pulley Blocks	169

Fig.		Page
110	Buoying Shore End of Heavy Cable	170
111	Hauling Cable on Shore by a Locomotive	171
112	An Iceberg	172
113	<i>Teredo norvegica</i>	173
114	<i>Limnoria lignorum</i>	174
115	Bone of Swordfish in Cable	175
116	Taking-up Machine	179
117	Under-running a Cable	180
118	Grappling Iron	181
119	Buoy	181
120	Mushroom-shaped Anchor	181
121	Cable Anchored and Buoyed	182
122	Flag Buoy	183
123	Removing a Buoy	184
124	Buoying the Cable	185
125	<i>The Great Eastern</i>	187
126	<i>The Great Eastern</i> raising Cable	188
127	The Atlantic Cable	189
128	The Paying-out Machine	191
129	Cable Suspended by a Buoy	192
130	French Form of Daniell's Battery	195
131	Bréguet's Form of Daniell's Battery	196
132	Thomson's Daniell's Battery	197
133	Siemens-Halske Battery	198
134	Minotto's Battery	198
135	Minotto's Battery (modified)	198
136	Thomson's Battery for Siphon Recorder	199
137	Thomson's Battery for Siphon Recorder	200
138	Callaud's Battery	201
139	Callaud's Battery (simpler form)	203
140	Meidinger's Bell	203
141	Callaud's Battery (American form)	204
142	Grove's Battery	204
143	Leclanché's Battery	205
144	Leclanché's Battery (modified).	205
145	Diagram of Battery Connections	208
146	Wheatstone's Single-needle Instrument	212
147	Wheatstone's Single-needle Instrument	213
148	Wheatstone's Single-needle Instrument (with keys)	214
149	Single-needle Manipulator	215

Fig.		Page
150	Single-needle Manipulator	216
151	Keys and Connections	216
152	Keys and Connections	217
153	Thomson's Mirror Galvanometer	217
154	The Distributor Key	218
155	The Water Resistance	219
156	Diagram of Connections	219
157	Diagram of Connections	219
158	The Siphon Recorder	220
159	Smith's Commutator	226
160	Diagram of Connections	227
161	The Siphon Connections	228
162	Connections of the Morse Receiver (diagram)	229
163	The Morse Instrument (Siemens')	230
164	The Morse Instrument (Digney's)	230
164 α	The Morse Instrument	231
165	Relay Connections (diagram)	232
166	Siemens' Polarized Relay	233
167	Siemens' Polarized Relay (contacts)	234
168	The Morse Key	235
169	The English Post-Office Key	236
170	Wheatstone's Perforator	238
171	Wheatstone's Perforator (diagram)	240
172	Wheatstone's Perforator (diagram)	241
173	Wheatstone's Receiver	242
174	Morse Printer	243
175	Diagram of Connections	245
176	Hughes' Printing Telegraph	247
177	Electro-Magnet	249
178	Diagram of Duplex Telegraphy	251
179	Illustration of Duplex Telegraphy	253
180	Diagram of Duplex Connections	254
181	Diagram of Artificial Line	257
182	Diagram of Artificial Line	257
183	Diagram of Duplexed Cable	259
184	Distributor for Telegraph Offices	261
185	Lightning Conductor	262
186	Bright's Protective Apparatus	263
187	Thomson's Mirror Galvanometer	266
188	Diagram of Connections for Faults	268

Fig.		Page
189	The Resistance Box	269
190	Railway Signals	272
191	Railway Signals	274
192	Railway Signals	275
193	Laying a Military Field Line	281

THE TELEGRAPH.

INTRODUCTION.

WE need not inform our readers that the purpose of the telegraph is the communication of thought at very great distances. That telegraph is the best which accomplishes the operation in the shortest possible space of time.

In order to convey thought to a distance we must express it in signs which shall affect the senses at the distant point.

In order to convey it rapidly, the sensible signs expressing it must be produced as rapidly as thought itself, and they must succeed each other without delay.

The science whose application constitutes the telegraphic art, comprises therefore the study of three main problems :—

1. To discover that physical agent which is most rapidly transmitted to the greatest distances, and is there capable of impressing our senses by its action.

2. To contrive a system of signals in which the manifestations of that agent are rapidly transmitted and are likewise varied.

3. To express thought by means of these signals in the quickest, clearest, and most general manner possible.

These three problems resolve themselves into an infinite number of important and difficult questions, worthy of being the subjects of many experiments, and of special investigation which might occupy a lifetime, and enrich science by new discoveries. But to make these facts practically available in telegraphic art, all the above-mentioned problems must be studied and solved together ; for if we lose sight of any one of them, the results we may obtain will probably be incapable of useful applications.

The agents capable of being used in telegraphy are four in number :—

1. Motion of translation. (The pneumatic telegraph is the most perfect type of this kind of transmission.)

2. Sound. (The acoustic telegraph aided by electricity has produced the telephone.)

3. Light. (Optical telegraphs, applied more particularly to armies in the field and to shipping, offer an advantageous method of communicating in cases where the electric telegraph cannot be used.)

4. Electricity, which in the electrical telegraph supplies the quickest and most complete method of rapidly transmitting despatches to very great distances.

Motion of translation as effected by railways, even if we suppose the speed to be the highest practicable, does not attain a velocity sufficient to render this means of transporting written correspondence comparable to telegraphy.

Pneumatic tubes have largely aided telegraphy for short distances in large towns, and the rapid motion that can be imparted by pressure to a current of air enclosed in an underground tube far surpasses the speed of a railway train.

There is now reason to believe that this quick method of transmission is capable of being extended to great distances, and we shall no doubt before long have pneumatic tubes with relays, capable of passing despatches over considerable distances without interruption. The despatch of letters by post might thus be accelerated to a very great extent.

Sound obviously presents greater capabilities of speed than any motion of translation. As everyone knows, it passes through the air at the rate of 1,100 feet per second, while through water and solid bodies its velocity is still greater.

But although sound was used by the ancients in telegraphy, it was seldom otherwise than as a simple conventional signal, and in this way its range never exceeded the distance of 1,000 yards. It has been reserved for our own age to produce the telephone, which transmits the sounds of articulate speech to very great distances. There is indeed reason to expect that it will not be long before the telephone will have been so perfected as to carry the sounds of articulate speech to distances as great as those passed over by the electric telegraph.

After electricity, light is the natural agent with the greatest velocity of propagation. It is also the one that most readily impresses our senses, and it does so from the greatest distance. Its velocity is such that it can be expressed only in the smallest fraction of time, even in its passage over a distance equal to the longest line of telegraph.

Then, whether we employ artificial light for transmitting signals, or utilize the direct or diffused light of the sun, no special conductors are required between the stations in order to make luminous beams or opaque bodies perceptible; the signals are conveyed with the speed of thought. After electricity, light therefore presents all the advantages of velocity, variety, certainty, and economy, except only that atmospheric conditions may frequently interfere with the transmission of signals. In spite of this inconvenience, optical signals are still much used, and even at the present day are of great service to ships, and to armies in the field.

Electricity is the true telegraphic agent, and to it especially does the telegraph owe its present development. And as it has now been allied with acoustical phenomena, it probably will soon be allied with optical phenomena also, and indeed be associated with other serviceable physical agents. We may then hope that an extension of the range of visual sense will soon follow that of the auditory sense, and that electricity is destined to greatly enlarge the present sphere of our material and intellectual life.

Science certainly has much yet to reveal to us, and the four physical agents, the effects of which we have just now briefly mentioned, will no doubt at some time be so combined as to supply mankind with the most perfect means of telegraphy.

In the following pages we shall examine the different systems of telegraphy, founded on the four above-mentioned physical agents, but we shall of course devote the largest space to the electric telegraph.

PART I.

OPTICAL TELEGRAPHY—ACOUSTIC TELEGRAPHY— PNEUMATIC TELEGRAPHY.

CHAPTER I.

OPTICAL TELEGRAPHY.

System of the Ancients—Various Methods before Chappe's Telegraph—Aërial Telegraph—Leseurre's Heliograph—Mance's Heliograph—Its application to the Service of the English Army in Afghanistan—System proposed by Sir William Thompson for distinguishing one Lighthouse from another.

IN his "Art of Signals," published at Hanau in 1795, Major Bouchercœder states that the art of telegraphy dates from the building of the Tower of Babel in the year B.C. 2247. This structure, he thinks, must have had for its special purpose the establishment of a central point of communication between the different countries then inhabited by mankind.

Scripture also relates that columns of fire and of smoke were used to lead the Israelites across the desert after their flight from Egypt.

The idea of attaching a signification to the appearance of fires on heights is so natural that traces of it are found among various savage tribes in Africa.

History and poetry have preserved certain traditions which prove that the art of telegraphy was used in heroic times.

Hannibal erected watch-towers in Africa and in Spain in order to transmit phrases by signals. The Romans adopted this method, and wherever they extended their conquests, they established rapid communications which enabled them to maintain their power over the conquered nations. Remains of these towers still exist in France. Those of Uzès, Bellegarde, Arles,

and of the Valley of Luchon, were occupied by watchmen who rapidly transmitted news from the adjoining countries.

The telegraph represented on Trajan's column is the only description of a Roman telegraphic station that has come down to our days. This station is surrounded by palisades; its second story has a balcony, and the building is surmounted by a small tower.

The Arabs and the Asiatics practised the art of conversing by means of visible signals, and the Chinese erected fire-machines on their great wall of 188 leagues in length, in order that the alarm might be given along the whole frontier that divided them from the Tartars, when some horde of that race were threatening them. They, like the Indians, used lights so brilliant that they penetrated fogs, and neither wind nor rain could extinguish them. The English, having learnt in India the composition of these fireworks, used them in the operations of the great trigonometrical survey by which the observatories of Paris and of Greenwich were connected in 1787.

These operations were conducted on one side by Cassini, Méchain and Legendre, and on the other by Roy and Blagden, and by them not only was a perfect triangulation effected by the use of fireworks, and even of ordinary reflecting lamps, but there was besides an exchange of signals from the opposite shores of the Straits of Dover. The possibility of a telegraphic communication across the Channel was therefore demonstrated as early as 1787.

Francis Kessler, an enthusiastic patron of the occult sciences, was the anticipator of the optical telegraph, now used in the army. He enclosed his telegraph in a barrel containing a lamp with its reflector. In front of the barrel was a moveable screen which could be raised or lowered by means of a lever. The screen raised once indicated the first letter of the alphabet, raised twice the letter B, raised three times the letter C, and so on. We shall presently see how the Morse alphabet signals may be represented by similar methods. The alphabetic system was in vogue at the period of which we are speaking, and it has reached down to the present time. In 1684, the celebrated Robert Hook described before the Royal Society of London, his system of signals formed of

planks of various shapes painted black, and which could be raised between slides.

Telegraphy by means of opaque bodies has continued in use for ships, especially as a means of indicating to mariners the heights and movements of the tides in ports. For this purpose balls with black bands are hoisted up on an apparatus formed of a mast and a yard. These balls stand out quite black against the sky. A ball placed at the intersection of the mast and yard indicates a depth of water of three metres throughout the whole length of the channel. Each ball placed on the mast below the first, adds one metre to the depth of water; if placed above it adds two. A ball hoisted at the end of the yard represent a quarter of a metre when it is to the left of the mast, and half a metre when it is to the right. Therefore only six balls are required to indicate the depth of the water, each quarter of a metre from three metres to eight and three-quarters.

These signals may be made at night by substituting lanterns for the balls, and using a coloured light to mark the point at which the yard crosses the mast.

To indicate the flow of the tides, a white flag with a black cross, and a black pendant in the form of a vane are used. These flags are hoisted as soon as there are two metres of water in the channel, and they are taken away when the water has again come down to that level. During the flow of the tide the pendant is above the flag; at the time of high water the pendant is taken away; and during the ebb the pendant is below the flag.

When the state of the sea prevents entrance to the port, all these signals are replaced by a red flag, also hoisted on the top of the mast.

This digression has withdrawn us a little from the history of visual telegraphs, but we thought the foregoing details would not be without interest.

Bertin, in his "*Curiosités de la Littérature*," informs us that the Marquis of Worcester laid claim to the invention of a hundred new machines, and asked Charles II. of England a certain sum of money to make them known. This was refused. It has been said that the telegraph and the steam-

engine were amongst these inventions, but no trace now remains of the results obtained in these researches.

Towards the end of the seventeenth century, Amontons and also Marcel made some experiments, as we know, although the machines and the drawings of these inventors have been lost, and Marcel has not left even a description of his plan. He did not wish to have his method made public until it had been adopted by the king; but Louis XIV. was then old, and Marcel got no answer to his petition. Dupuis, the author of "*L'Origine de Tous les Cultes*," in 1723, laid before the government a scheme of alphabetic telegraphy. It was not until ten years afterwards that he made a trial of it at Ménilmontant in order to communicate between his house and that of a friend at Bagneux. When Chappe's telegraph was laid before the Legislative Assembly in 1792, Dupuis, who was one of the members, abandoned his plan.

In 1783, Linguet offered the French government a method of transmitting to the greatest distance intelligence of any kind, even long sentences, with almost the speed of thought. This plan, which Linguet thought would obtain his release from the Bastille, was tested before commissioners appointed by the government. It was not adopted, and no trace of it remains.

Monge seems also to have proposed, before Chappe, a signal telegraph which was erected on the central pavilion of the Tuileries, but was never used.

It seems therefore that many scientific men studied the art of signalling, before Chappe and his brothers introduced their system of optical telegraphy into France. Nearly all their predecessors were content to communicate a few words from one station to another station, and this is one reason why they failed. But in order to transmit a considerable number of signals to great distances, it is evidently requisite that the stations must be numerous. The brothers Chappe tried experiments among themselves with a rude apparatus for corresponding by signs, consisting of a wooden rule turning on a pivot and carrying two smaller rules of half the size at its extremities. They afterwards made some attempts at transmitting signals by electricity. Claude Chappe, the most ingenious of the five brothers, had contrived a method of corresponding by help of two synchronous pendulums,

electrically marking the same figures. He carried insulated conductors to certain distances; but the difficulty of insulating them, the high electrical intensity required, and the dependence of the action on the state of the atmosphere, led him to think that his plan of communicating by electricity could never be realized.

It is curious to observe that Claude Chappe entertained for a short time the idea of utilizing the very agent which was destined to afterwards displace his own telegraph.

FIG. 1.

After many failures, however, Claude Chappe succeeded at length in perfecting a system of visual telegraphy in which signals were repeated from station to station, by means of an apparatus, the upper portion of which was composed of three pieces each capable of being separately moved (Fig. 1). The largest of these pieces, having the form of a very elongated parallelogram with two other pieces mounted at its extremities, can be placed in four different positions, namely, horizontal, vertically, or inclined at 45° right or left. Each of the attached moveable pieces, called wings, can be made to assume seven different positions as regards the principal piece, by

forming with it, above or below an angle of 45° , a right angle, or an obtuse angle, and by coinciding with it in direction. The three will thus produce 196 different figures, which may be regarded as so many simple signals, to each of which any determined meaning may be attached. It will easily be seen that by placing in any direction a series of such machines, each of which repeats the movements of that which precedes it, the figures made at the first station, are transmitted to the end of the line, as are the ideas that have been

attached to them, of which the intermediate agents may however have no knowledge. In order that it may be known that the signal has been properly given from the summit of the cabin, there is placed within, at the lower part of the posts that support the telegraph, a repeater, which serves as handle for giving movement, thus at once taking and giving the figure which has to be formed at the upper part.

Such is the system of Claude Chappe, which he fortunately got adopted, thanks to the good offices of his brother Ignatius, who had been appointed member of the Legislative Assembly in October, 1791. By the aid of his relative Delaunay, formerly Consul of France at Lisbon, Claude Chappe drew up a secret vocabulary of 9,999 words, in which each word was represented by a number. Such were the results presented by Claude Chappe, on the 22nd March, 1792, to the Legislative Assembly, before whom he was admitted. In the speech which he made on this occasion he asked the Assembly that, if the invention should be successful, he should merely be recouped for the expenses of his experiment.

The examination of his machine was referred to a committee ; but it was not until the 1st April, 1793, that Romme, the secretary of this committee, reported in favour of the adoption of Claude Chappe's system of telegraphy. Romme ended his report by asking the Assembly for a vote of the money necessary to establish a preliminary experimental line. The Convention voted the insignificant sum of 6,000 francs, at the same time directing the committee to appoint a commission before whom the new apparatus should be worked. The members of this commission were Arbogast, Daunou, and Lakanal, to the last of whom Claude Chappe was indebted for the final adoption of his telegraph by the Convention. An experiment made on the 12th July, 1793, had so distinctly told in favour of Chappe's system that there was no longer room for hesitation. Lakanal, who had been appointed secretary to the commission, made a deep impression on the Assembly when he read his report before it, on the 26th July, 1793. He wound up by proposing to confer on Claude Chappe the title of Telegraph Engineer with the stipend of a lieutenant of engineers, and proposing also that they should consider what lines of communication the Committee of Public

Safety required to be formed in the interests of the Republic. The Convention embodied Lakanal's proposals in a decree. Officially adopting Chappe's telegraph, it directed the Committee of Public Safety to cause a line of communication, with the necessary number of stations, to be established. Chappe, thus appointed Telegraph Engineer received the pay of 5 francs 10 sous per day, so that his position was assimilated to that of a lieutenant of engineers.

The Committee of Public Safety, thinking that Chappe's telegraph would enable the commanders of the army to communicate rapidly with each other, decided that the telegraphs should first be established in the vicinity of besieged towns, and that the lines should pass from the limits of the frontiers, that is to say from Lille and from Landau to Paris.

This line was ready for use in *Fructidor, An. II.* (August, 1794), and the circumstances connected with the first despatch deserve to be related.

The town of Condé had just been retaken from the Austrians. On the same day, namely the 1st September, 1794, at noon, a despatch forwarded from the tower of St. Catherine at Lille passed from station to station until it reached the dome of the Louvre at Paris, just at the moment the Convention was about to sit.

Carnot ascended the tribune, and with a sonorous voice, announced that he had just received by the telegraph the following news :—

“Condé is restored to the Republic ; its surrender took place at six o'clock this morning.”

This news was received with thunders of applause, and every voice was raised to honour the new invention, so brilliantly inaugurated for the glory and safety of the country.

Chappe's aërial telegraph underwent divers vicissitudes under the Directory and under the Empire. Nevertheless under these governments, as well as under the Restoration, many lines were established in France ; but Chappe was not to witness these developments of his cherished invention ; for, disgusted with the little esteem in which his invention was held by the emperor, and suffering acutely from a chronic disease of the bladder, he gave way to despair, and cut his own

FIG. 2.—Chappe's Aërial Telegraph.

throat on the 25th January, 1805. Besides the monument which was erected to him in the cemetery of Père Lachaise, there is under the lofty signal-tower in the Rue de Grenelle-Saint-Germain, from which so many historical despatches have issued, a small memorial to mark the spot where Claude Chappe committed suicide.

Claude's brothers, Ignatius and René, were appointed directors, with salaries of 8,000 francs per annum. They had to resign in 1830, when a royal order appointed M. Marchal provisional administrator, and from that time to 1848, the aërial telegraph remained stationary. M. Ferdinand Flocon was at that date appointed administrator of telegraphs, but was succeeded in 1849 by M. Alphonse Foy, who had previously held the office under Louis Philippe. It was M. Foy who had the honour of introducing the electric telegraph into France. He entrusted M. Bréguet with the task of constructing a French apparatus for reproducing the signals of the aërial telegraph. This difficult problem was solved by M. Bréguet in the most elegant manner; but the signal apparatus soon became merely alphabetical, that is to say, the signals of the aërial telegraph were speedily reduced to the twenty-five letters of the alphabet, supplemented by the figures and other signals that are met with in all the other systems.

The aërial telegraph was also used by our troops during the Crimean war, and M. Inspector Carette utilized it on this occasion as a field telegraph. Submarine telegraphy, then scarcely two years old, was also brought into the Crimea by the English, who connected Varna and Balaclava by laying in the Black sea a gutta-percha covered wire, which lasted about six months. The new and the old telegraphy were by these circumstances brought face to face. Aërial telegraphy, however, had had its day, and since then it has entirely disappeared.

Other European nations have had visual or aërial telegraphs, which, although inferior to Chappe's system, have nevertheless proved of great service for distant communications. It is unnecessary here to describe these inventions, which are similar to the aërial telegraph.

The visual telegraph has not been abandoned even at the present time. Systems of optical communication have recently been adopted, especially in the last wars, and the experiments

made by the French Telegraph Administration in 1870, enabled communications to be made between Havre and Honfleur, when the submarine cable was broken, and the like has occurred at other places, especially between Paris and the detached forts. The Prussians also used red and green signals during the siege of Belfort. The committee for organizing the national defence of Marseilles proposed in November, 1870, to the government of Tours, a system of night signals founded on the emission of rays of light for a longer or shorter period, so that the Morse code might be used. This proposal was considered at Tours by a specially-appointed committee. The object of this scheme was to communicate with Paris from without, over the first Prussian line of investment. This line had at that time a radius not greater than twenty-seven miles, and the proposed communication might have been effected had prompt measures been taken. The great extent that was given to the second line of investment caused the inventor to abandon his project. In the meantime, M. Lissajous who had left Paris in a balloon with a similar project, showed the provinces how easy it would have been to establish a system of communication. He got M. Santi, the skilful Marseilles optician, to construct apparatus founded on the same principles, but these apparatus did not come into use, or at least not during the war. They have, however, been taken up since by the military Telegraph department and are now used in our army.

The military telegraph administration has daily experiments made at the military school at Saumur, and once a year experiments on the large scale are made at the camp at Saint-Maur. The apparatus used at the present time is that proposed by Colonel Mangin, and it may be thus described. A rectangular box, A, Fig. 3, is divided into two equal parts by the diaphragm, B, which has a very small round opening at C. A convex lens is mounted in the front part of the box. This lens has a diameter of $5\frac{1}{2}$, $9\frac{1}{2}$, or $13\frac{3}{4}$ inches, as the case may be. The first two diameters are those most in use. In front of the opening, C, is placed a screen, D, capable of turning on an axis in such a manner as to open and shut the orifice by means of a handle at M. A touch of the finger suffices to raise this screen, and it falls back into its place by its own weight.

The second compartment of the box has a lamp with a reflector which sends back rays that would otherwise be lost. The action of the apparatus at night will easily be understood. It is only necessary to give a longer or shorter touch to the handle to send long and short flashes which will correspond with the dots and dashes of the Morse code. The telescope, L, placed outside of the box, serves to find the distant station. For this purpose it is only necessary to scan the horizon with slight vertical movements, when the ray of light which

FIG. 3.

indicates it will easily be found. For when this is being sought each station will keep the screen, D, of its apparatus up. The telescope must be perfectly parallel to the ray of light sent out by the lamp. It is therefore fixed to the box once for all, and, moreover, has adjusting screws, by which when the image of a point on the horizon has been focussed on the centre of a piece of ground glass at the end of the second chamber as in a photographic apparatus, this image can at the same time be caused to appear in the telescope at the intersection of a vertical and a horizontal wire; then the parallelism is perfect.

FIG. 4.—Mangin's Military Telegraph.

The same apparatus is used in the daytime, but the lamp is then removed, and its place is occupied by a lens for the purpose of condensing the solar rays to the position of the flame of the lamp. In the apparatus with a lens of $9\frac{1}{2}$ inches diameter, two small plane mirrors, which are adjusted by hand, throw the solar beam in the proper direction. The diurnal motion of course requires the mirrors to be adjusted from time to time, but this is easily done by hand every five minutes. In the larger apparatus a heliostat is fixed on the upper part of the box, and is provided with clockwork by which the mirror is made to follow the apparent motion of the sun, so as to direct the beam always in the same direction. In cloudy weather the night apparatus can be used for signaling in the daytime, as a petroleum lamp is able to give perceptible signals even at a distance of 12 miles.

Experiments have been made with many apparatus at the camp of Saint-Maur. Amongst the rest was one with polarized light, in which the signals were produced by the polarization of the beam when a Nichol's prism was introduced into its course. Thus, the beam of light being uninterrupted all the time, the signals would not be perceived by strangers.

An Italian system, with red and green lights, has also been successfully tried. In this case also the beam of light continues without eclipse, and is merely tinted by the introduction in its path of red or green glasses which the operator holds in his hand, and uses as easily as a pair of drumsticks.

M. Mercadier has produced an apparatus in which the combustion of the lamp is quickened by a jet of oxygen gas. An apparatus of this kind invented by Mr. Walker has for some time been made in England: it is manufactured at Silvertown, and it includes even the apparatus required for making oxygen gas in the field.

In all these systems the speed of transmission amounts to twelve or fifteen words per minute, and by experienced operators it may be increased to twenty words per minute.

It was feared that the persistence of the impressions of the signals upon the retina would necessitate slow transmission. But it has been found in practice that there are no grounds for that supposition. The running together of signals that

sometimes takes place is owing only to bad manipulation. Just as an operator working the Morse signals through a long cable should be perfectly aware of the effects of currents in his line, and should regulate his manipulation accordingly, so also ought the sender of visual signals to space them in such a manner as to make them distinct to the eye. In this respect the handle of the Mangin apparatus seems to us defective; but it might easily be modified so as to present absolutely the same form and effects as the ordinary Morse key.

The heliograph invented by M. Leseurre, inspector of telegraphs, was first utilized in Algeria. Marshal Vaillant exhibited this apparatus before the Académie des Sciences (*Comptes rendus*, 16 June, 1856). M. Leseurre has himself described his apparatus in the *Annales télégraphiques* for October, 1855. This inventor, who unfortunately died at Pau in 1864 at the early age of thirty-six, had for his special object the establishment of telegraphs in the Southern part of Algeria, where at that time it was scarcely possible to construct electric lines, or even aërial telegraphs.

The continual sunshine which in South Algeria produces an exceptional condition of the soil unsuitable for ordinary telegraphs, offers also an exceptional agent for signalling by a system more effective than Chappe's aërial telegraph. Mirrors suitably arranged can reflect the rays of the sun in such a manner as to form signals, and even record them.

The range of this signalling power is limited only by the rotundity of the earth and by the absorption of light in its passage through the lower strata of the atmosphere.

For practical use, a simple apparatus is required with certain and rapid action, so that it may be worked by men of ordinary intelligence.

M. Leseurre has solved this problem in a very elegant manner. The annexed Fig. 5 will give an idea of his apparatus which we shall now also describe. To make the apparatus available at any hour of the day, M. Leseurre, knowing that the sun in its diurnal movement describes a circle round the polar axis, placed in the polar direction an arm carrying a mirror with its normal forming with the arm an angle equal to half the angular distance of the sun from the pole. By turning this arm on its bearings, every time that

the normal to the mirror passes through the meridian then occupied by the sun, the reflected beam will be projected towards the pole.

A second mirror, the centre of which is on the prolongation

FIG. 5.

of the arbor of the first, and so inclined that the rays it receives from the first are reflected to the distant station, completes the apparatus. This second mirror, of course, remains in one fixed position.

Nothing can be simpler than the working of this apparatus. It is necessary only to turn round the axle of the moveable mirror as often as the flashes are to be produced. M. Leseurre also contrived a screen made of moveable pieces like a Venetian blind (Fig. 5a). When the laths of the blind are open the beam passes, when they are closed the light is shut out. A handle, *a*, was provided for working the laths.

The amount of light reflected does not change during the day, since the inclination of the revolving mirror to the reflected ray remains constant. But as the sun's declination

FIG. 5a.

varies from day to day, M. Leseurre placed in front of the revolving mirror a telescope with its optical axis parallel to that of the mirror. By observing the reflected rays through this telescope the operator was enabled to perfectly adjust his apparatus.

M. Leseurre's apparatus did not come into working operation in Algeria, but it was tried with the most satisfactory results at the Observatory of Paris, in presence of the Minister of War and the Director General of Telegraphs.

The apparatus could be used with the Chappe code by means of conventional signals, as well as for the long and short emissions of light that constitute the Morse alphabet.

Mr. Henry C. Mance, the electrician of the Persian Gulf submarine telegraph, by adopting the idea of Leseurre, succeeded in

bringing into use a similar system for the service of the English troops in Afghanistan, where it proved of great advantage.

The instrument (Fig. 6) is supported by a light but firm tripod, has a movable disc, P, capable of a quick or slow motion, which is imparted by a tangential screw. A circular mirror, M, is supported on a foot surmounted by a semicircular

FIG. 6.

frame in which the mirror turns on pivots. The mirror has a small aperture in the centre by which a sight may be taken from behind. On the disc an ordinary Morse key is connected with the upper part of the mirror, to which its movements are communicated by means of a steel rod capable of adjustment. The apparatus can, moreover, be adjusted to suit the position of the sun and the place towards which the signals are to be transmitted. The lever of the Morse key changes the inclination so as to throw the reflected rays to a given point. The mirror may also be moved by hand and adjusted in its

position correctly or approximately. The complete revolution of the mirror serves as in Leseurre's system to sweep the horizon with a luminous beam, which attracts the attention of the corresponding station.

At about four yards in front of the apparatus is a staff which acts as a mark between the centre of the heliograph and the corresponding station. On this staff two pieces, H , H^1 , slide up and down. One of these is placed in a line between the mirror and the corresponding station. The other one carries a horizontal wooden cross-piece, H^1 , about a foot long. When the apparatus is not in use, the ray of sunlight reflected by the mirror falls upon the latter. But when the Morse key is touched, the ray is carried towards the upper slide, H , in the line of communication. The operator, on seeing the upper slide illuminated every time he presses the key, is certain that his signals reach the corresponding station exactly. In England the signals sent by this apparatus can be seen at the distance of 50 miles; but in India and in similar climates they carry to a distance of 70 or 100 miles; and the rotundity of the earth appears to set the only limit to their range. The adjustments which have to be made in the position of the mirror, in consequence of the sun's daily motion, are easily effected by means of appropriate regulators, even while the signals are being transmitted.

It will be observed that the upper slide stops the luminous rays from reaching the distant station when the Morse key is pressed. In this system, therefore, the signals are given by stopping the light; that is to say, the solar rays reflected by the mirror continuously indicate to the distant station the position of the other; and it is when the light disappears that a signal is being made. In this consists almost all the novelty of the system; the application of the Morse key to a system of correspondence by rays of light dates farther back, and was adopted as early as 1863 by the squadron engaged in laying the submarine cable in the Persian Gulf. MM. Lissajous and Ternant had also in 1870 proposed a system of optical telegraphy by light shown by means of a Morse key, and the application by Mr. Henry C. Mance of this instrument dates at farthest only from 1877.

The heliograph apparatus of Mr. Mance weighs only 6 lb.,

and can be carried by one soldier. It has the advantage of being available between the advanced guard and the main body of an army, and in Afghanistan and Zululand it superseded the flag signal commonly used in the English army between detached bodies of troops. It has everywhere been used where the electric telegraph could not be employed, and although it has occasionally failed from the want of sunshine, yet, for short distances, it has been found serviceable even under a cloudy sky.

Sir W. Thompson has lately examined for the Ship-Masters' Society, the various kinds of luminous signals now in use for distinguishing lighthouses.

In his opinion, neither revolving lights of definite periods, nor lights with flashes at intervals of three or four minutes, are sufficient to ensure the safety of mariners, and the same is the case with coloured lights.

Sir W. Thompson proposes to overcome the difficulty by a system of eclipses produced by revolving screens, which shall produce intermittent extinctions. The system is to be founded on the Morse alphabet, and each lighthouse is to be represented by a letter. In support of his proposition, the eminent physicist has referred to the good results obtained with this system for the last three years at the Hollywood Bank Lighthouse, near Belfast, where the signals consist of two short eclipses followed by a long one. These are produced by means of a copper ring carrying a series of screens, which is turned by wheelwork.

This appears to be an excellent system ; for a lighthouse sending out intermittent signals forming the first letter or the first two letters of its name according to the Morse code, would be immediately recognised by every mariner knowing in what seas he is sailing ; and in this way an international code of signals might be formed of the highest utility for safe navigation.

The system is, in fact, one which cannot fail to be speedily adopted ; the more so as it can be adapted to existing lighthouses without any difficulty, and at a trifling expense.

The same thing will doubtless be done for shipping. All ships having steam power will certainly before long be fitted with the electric light, and the use of intermittent signals in

the Morse code to distinguish each ship would be highly useful, either for naval manœuvres, or for corresponding with ports at a distance, and also for the avoidance of those dreadful collisions which are only too frequent.

It appears, then, that whether for telegraphing, or for light-houses, or for ships, the employment of intermittent signals will become indispensable ; and that by the help of movable screens, such as are now used in military telegraphy, they can easily be produced without any practical inconvenience.

CHAPTER II.

ACOUSTIC TELEGRAPHY.

Ancient system—Speaking Tubes—String Telegraph—Telephones—Telephone Companies.

THE historian Diodorus relates that a king of Persia communicated between Susa and Athens by the voices of the sentinels he had placed from distance to distance. The intelligence was conveyed in one day over a space of thirty days' march.

Kircher in 1550, and Schwenter in 1636, wrote treatises on auricular signs, and proposed to translate the letters of the alphabet into musical notes.

Bernouilli, in his "Travels," mentions that he saw at Berlin an instrument formed of five bells, which could express all the letters of the alphabet.

It is said also that Alexander the Great discovered a mode of making himself heard by his whole army, at a distance of four leagues, by means of a speaking trumpet (*tuba stentorophonica*). A representation of this instrument is preserved in the Vatican.

Morland invented speaking trumpets which gave great intensity to the voice. The king of England was, in 1670, presented with one of them, which enabled words pronounced a mile and a half off, to be audible even against the wind. Two or three of these trumpets were so far improved by Morland, that the Warden of Deal wrote to the First Lord of the Admiralty that a conversation could be carried on with vessels at a distance of three miles from the shore. Morland has left only imperfect descriptions of his speaking trumpets, but he showed that the tubes must be gradually enlarged towards their outer extremity, in order to reinforce the sound.

In 1782, Dom Gantey made some experiments on the pro-

pagation of sound in the pipes which carried the water from the pump at Chaillot, and, it is stated that with three hundred pipes of a thousand toises each, despatches could be sent one hundred and fifty leagues in fifty minutes. In 1783, he published at Philadelphia a prospectus which shows that he had proposed to the Académie des Sciences absolutely new methods of sending a despatch with great speed.

The two discoveries were examined by the Académie, and MM. Condoret and Milly, the commissioners appointed to report upon them, stated in their report dated 15th June, 1782, that as regards the first discovery, the means proposed appeared to them practical, ingenious, and novel; "that it had no resemblance to any methods previously proposed, and that by it a signal might be given at a distance of thirty leagues in a few seconds and without intermediate stations; that the apparatus would be neither expensive nor cumbersome, and that they had appended to Dom Gantey's paper the grounds of their belief in the possibility of the method, which the author wished to keep secret." This secret was, in fact, placed under seal, and doubtless still remains in that condition in the archives of the Académie des Sciences.

The same commissioners were appointed to report upon the second method; but Gantey asked them to postpone their examination of it until he had obtained the money for making some experiments in their presence. He opened a subscription, which proved inadequate for the expense that would be incurred in the trials he wished to make, and the Report was never presented.

M. Biot devoted some attention to the investigation which Dom Gantey intended to make. He read a paper before the Académie des Sciences, containing an account of several beautiful experiments on the propagation of sound through solids, and through air contained in very long tubes. He showed that sound is propagated in solid bodies more rapidly than in air, and he estimated the difference with a sagacity and precision that exemplify the exactitude of observation introduced into modern physics.

Sound is of great service in telegraphy. It is well known that from the sounds made by the Morse key or by the receiving apparatus the despatches may be read by the ear alone.

This even gives telegraphic superintendents a means of control and supervision over their offices.

Mr. Neale, the electrician of the North Staffordshire Railway, has recently improved the American apparatus which are read by sound, by inventing for use on railways, telegraphs in which the despatch is read by the ear instead of by the eye. His first object was, of course, to increase the sound and make the signals more distinct. For this purpose he transmits the movement to a strip of iron which on one side strikes against a metallic point, and on the other against a wooden peg, and thus produces two different sounds. The whole is enclosed in a case which is constructed to reinforce the sound. The receiving clerk, in whatever part of the office he may be placed, may write down the despatch as fast as he hears it without even looking at the instrument. The call signal may be heard outside of the office even when the doors are closed, and thus the cost of a call-bell is dispensed with, which is a great advantage for small stations.

Not all the methods that men have invented for corresponding by the propagation of sound have been put into practical use. There is a small apparatus called the *String Telegraph*, which seems to have been invented by Robert Hooke as early as 1667.

He says :—By means of a stretched cord, I have been able to instantly transmit sound to a great distance with a velocity as great as that of light, and incomparably greater than that of sound in air. This transmission can be effected not only with the cord stretched in a straight line, but also when it has several bends.

This simple apparatus might have rendered good service to mankind since the period of its invention ; but it has merely been employed as a toy for children or a medium for the conversations of lovers ; and further, has only been recently used in Europe, although it has long been utilised by imperfectly-civilised races, and is met with among the American Indians in the Far West.

We saw it used in the Pyrenees in a way that is worth describing. Two isard hunters, separated from each other by the height of a rock, communicated by means of a cord telegraph, the string of which was about 120 yards long. The

watcher below could easily see the isards without alarming them, and he described their movements to his comrade so as to indicate when the prey was within reach. It seemed that these mountaineers had made use of the Thread Telegraph ever since they had seen it in operation at Tarbes, when the idea of applying it to their pursuit occurred to them.

Is it possible that the String Telegraph suggested the idea of the electro-magnetic telephone? This is not certain; but it was only in 1854 that M. Bourseul conceived the idea that speech might be transmitted electrically. But before the telephone was thought of, we remember that long ago those who were engaged in the construction and maintenance of the telegraph lines were able to correspond with each other at a distance by means of the posts erected along the road. By striking one of these posts with a stone, and timing the blows so as to reproduce the Morse signals, we were often able to transmit orders to distances of several miles.

This is a circumstance well known to telegraph superintendents; and as the posts are generally accessible, our readers can easily avail themselves of this method of correspondence. The sonorous vibrations are propagated with a velocity of 5,544 yards per second through the iron wire used for telegraph lines, whilst the vibrations attain in air the velocity of only 350 yards per second.

The speaking-tubes that are used in nearly all large establishments are, properly speaking, telephones. They are generally made of metal, and when they are not too long, the voice is carried from one end to the other, with all its tones and inflexions. The known voices of different persons can always be recognised.

The diameter of the pipes is generally $\frac{3}{4}$ inch for ordinary lengths; but as the length becomes greater, or as the bends are more numerous, the voice is less distinctly heard. Beside, by the settlement of buildings, the tubes become displaced or broken, and often after a certain period they fail to make the voice heard.

By increasing the diameter of the tubes as they are longer, the communication may be made at a greater distance, but the question of cost has then to be considered.

During the siege of Paris, M. Casanova arranged a speaking-

tube 650 yards long between the advanced position at Billancourt and the fortifications. It was a brass pipe buried in the ground, and the orders were sent in the ordinary conversational tone, as if the correspondents were speaking to each other face to face. Unfortunately, we are not told what was the diameter of that tube.

A speaking-tube does not in general make the sounds audible to any but a single person who applies his ear to the bell-shaped extremity of the tube.

M. Niaudet, in his work entitled "*Téléphones et Phonographes*," to which we are much indebted, states that he remembers seeing, when he was a child, great funnels of a foot diameter which were used as the mouthpieces of the speaking tubes at M. Bréguet's. These funnels were attached to the ceiling of a room throughout the whole of which the sounds carried by the speaking-tube could be heard. When you wished to reply, you had only to turn towards this mouthpiece and to speak more or less loudly according to circumstances. During the day, the external noises somewhat confused the results, but in the silence of the night the least noise made in the communicating room was heard at the other end, as for instance, when the pages of a book were turned or when a pen was scratching on paper.

It will be seen that we should be aware of speaking-tubes, for sometimes they allow what is said in the room from which they lead to be heard by a person for whom it is not intended.

Speaking-tubes are always fitted with a whistle for calling the correspondent. Nearly every telegraphic arrangement requires some method of calling the attention of the person who is to receive the message. The optical telegraphs are the only ones without this means of preliminary warning, and they therefore require a continued attention to be directed towards the point from which the signals proceed.

The electric telephones having been completely described in other works, we do not here intend to do more than explain the principle of telephonic apparatus, and describe the practical systems which are already used by the Telephone Companies at New York, London, and Paris.

As regards history, we may state that in 1844, Page found

FIG. 7.—Telephonic Communication.

that a musical sound always accompanies the changes of magnetic forces in a bar of steel mounted in such a manner as to give out its acoustic vibrations.

In 1861, M. Phil. Reiss, of Friedrichsdorf near Homburg, discovered that a vibrating diaphragm may be thrown into movement by the human voice in such a manner that the rhythm and pitch of the sounds can be reproduced at a distance by means of an electro-magnet.

In 1874, Elisha Grey invented a method of electrical transmission, by which the intensity of the sounds, as well as their pitch and rhythm could be reproduced at a distance. He afterwards conceived the idea of controlling the formation of waves of electricity by means of the vibrations of a diaphragm capable of lending itself to all the modifications of the human voice. He thus solved the problem of the transmission and reproduction of articulate speech by an electric conductor.

In 1876, Professor A. G. Bell invented his now well-known form of telephone, in which the transmission and reproduction of articulate speech is accomplished by means of superposed magneto-electric currents. In the same year, Dolbear conceived the idea of substituting permanent magnets for the electro-magnets and batteries previously employed, and of using the same apparatus for both sending and receiving instrument, instead of using two instruments of different constructions.

In 1877, Edison applied to the telephone the discovery, made by himself a few years before, of the variation of the resistance of carbon and other inferior conductors when they are subjected to changes of pressure. By this means, he could not only vary the force of the battery current, in unison with the raising or lowering of the vocal sounds, but also obtain a louder and more distinct articulation.

Since then, Gower, Pollard, Hughes, A. Bréguet, Crossley, Paul Lacour, Preece, Blake, and many others have contributed to the development of this invention, which Sir William Thompson has called *the wonder of wonders*.

Into this little instrument, scarcely larger than the mouth of an ordinary ear-trumpet, the interlocutor speaks to his correspondent by setting up vibrations in a plate of iron. This iron, acting on the electro-magnet, produces currents of

electricity which, passing through the line to the corresponding station, excite the magnetism of a magnet in the circuit and thus set into vibration a plate of iron like that against which the original voice was directed. This iron plate speaks to the hearer, and speaks so distinctly that if three persons speak or sing all together at the other end, their voices can be distinguished and are heard as if they were themselves present. Is not this the crown of the edifice? We cannot but admire the genius of the inventors who have given us the means of speaking with friends at a distance, and of hearing the sound of familiar voices or the loved accents of a person with whom we can converse in spite of separation.

And what may we not yet expect from the telegraph and the applications of science, especially that of electricity, the marvellous agent that interpenetrates the whole of nature? If, instead of making jokes at Charles Bourseul in 1854, when he proved the possibility of a method of correspondence that has now been realised, people had encouraged that young inventor, whose idea was five years afterwards put into practice by Reiss, we should doubtless have had the telephone invented in France. The future will bring us many other wonders, for which, however, we are now prepared. Already, Edison's electro-motograph or motophone, in which a supplementary force is put in action by suitable contrivances, magnifies the sound of the human voice, and so increases its intensity as to make it heard by a large audience.

The telephone companies have not been long established in France, and the improvements they have introduced are but slowly making way with the mass of the public, which does not always perceive clearly its own interest. The monopoly of European governments is tending to disappear, and should not be regretted, for it has often weighed heavily on inventors, and proved an obstacle to the development of great inventions. The vast development of telegraphic inventions in England and in America is due entirely to the absence of this monopoly; and although England has adopted the doubtful policy of appropriating the internal network of telegraphs to the Post Office by buying up the great companies of the United Kingdom, she has never dreamed of taking out of the hands of private companies that immense system of submarine tele-

graphs, which, to the eternal honour of England, remains the finished example of what can be done by untrammelled industry and enterprise.

Two companies are soliciting the favour of the French public for telephonic correspondence in the great centres. The first of these companies has combined the Gower telephone with Blake's microphonic transmitter, which with Bell's telephone is to be made the basis of a third company.

The services of the two existing companies are now in operation, and the completion of their system of lines has been accelerated by their recent amalgamation. The *Compagnie Générale des Téléphones* first gave its subscribers the use of the Gower telephone, and with it we shall enter upon our notice of that kind of electric establishments.

In principle the Gower telephone does not in truth present any novelty; but the conditions of the instrument have been so well studied that this system can make a Bell telephone, *without a battery*, speak loud enough to be heard throughout a room; and it comprises besides a call-signal within itself. These happy results are owing to Mr. Gower's having to some extent emancipated himself from the theoretical ideas that were first put forward concerning the telephone—ideas which for some time impeded its progress. In fact, instead of damping the fundamental vibrations of the vibrating plate of the Bell telephone, as had hitherto been attempted, Mr. Gower endeavoured on the contrary to increase them by firmly fixing the vibrating plate on the cover of the mouth-piece, so that when struck it could emit a sound. He made the plate thicker, and enclosed the whole in a sonorous metallic cylindrical box. He also made the magnet of a particular shape, so that the two poles should be opposite to each other and at a very small distance apart, as in Faraday's system of electro-magnets.

This magnet is made with great care, and has sufficient power to lift ten pounds. It is placed at the bottom of a cylindrical box, and its poles, terminated by oblong iron cores surrounded by coils of very fine wire, are placed in the centre of the diaphragm.

The arrangement of the magnet, with its two poles surrounded by the coils, will be seen in Fig. 8.

The call is formed, for the transmitting station at least, by an opening made in the diaphragm, behind which is placed a harmonium reed. To set it in motion, a speaking tube is fitted to the mouth of the apparatus, and when this tube is blown into, the reed is thrown into vibrations which, being directly communicated to the diaphragm of the telephone, make it produce induced currents sufficiently powerful to cause the receiving apparatus to emit a comparatively loud sound like that of a horn. To transmit speech it is only

FIG. 8.

necessary to speak in front of the mouth of the acoustic tube as in the ordinary system.

The apparatus may, however, be so arranged as either to reproduce speech in a loud voice, or merely in a low voice as in the ordinary systems. When it is required to speak loudly, the mouth of the receiving apparatus must be provided with a speaking trumpet, as in Edison's phonograph, and the transmitter must be spoken into by applying the mouth to the opening of the speaking tube; the words being pronounced of course in a very loud voice.

When the apparatus is to be used as an ordinary telephone, the speaking trumpet of the receiver is replaced by an acoustic tube which is applied to the ear; the words pronounced in a

low voice at the transmitter are then heard with increased distinctness; and if the apparatus is provided with the before-mentioned speaking-trumpet, words pronounced in an ordinary tone even at the distance of twelve yards from the transmitter may be clearly heard. These effects are really of much interest, for you can attain the extraordinary result of carrying on a conversation without leaving your chair, even when the apparatus is several yards off. But your interlocutor must in this case speak into, and listen at, the acoustic tube with which the apparatus is fitted.

The *Compagnie Générale des Téléphones* has in no way altered this apparatus for public use. Each subscriber has of course an instrument fitted up in any room he may wish, where someone is constantly present, or is not so far off but that the apparatus may always be heard. I shall presently explain how in certain circumstances, such as in noisy or little-visited places, the difficulty of doing this is overcome.

At Paris, where this system of lines has been established, the subscriber is connected by an insulated conducting wire with the central office at No. 66, *Rue-Neuve-des-Petits-Champs*. The lines are at present partly aerial, and partly subterranean, passing into the sewers. These lines have been constructed by government engineers.

The insulation of the wires is a very important matter; for it is well known that two lines running side by side, affect each other so that the words that are passing in one may be heard in the other. This is a serious inconvenience, which leaden covers and all other plans that have hitherto been proposed have failed to remove. It seems, however, that Mr. Gower has succeeded in obviating this by means of a particular method of insulation, which is at once secure and inexpensive. The wires are of different colours in the several cables, as are the cables themselves, so that in case of an accident to any line its course may be traced, as for instance the blue wire of the black and red cable. When the cables reach the central office the bundles are separated, and the cables are unwound, the wires being distributed to their several places.

It is here that the difficulties begin, and in order to understand what they are, let us imagine the system at work. For

simplicity each subscriber is distinguished by a number ; and we will suppose, if you please, that No. 5 wishes to speak. He takes his telephone and blows in order to make the signal sound, which will of course be heard at the central office.

The first idea is to provide the wire of each subscriber with a telephonic signal at the central office ; so that when one of

FIG. 9.

them sounds, the clerk at the office may hear it and answer. But it is not sufficient for the sound to be heard, the clerk must know whence it proceeds. Suppose he is in his office among thirty or a hundred telephones : when one of them sounds, how is he to know which it is ? Each might have a special note, but then a fine ear would be required to recognize these notes, and such musical discrimination could not be

expected. Further, if the clerk should have made a mistake and the signal be over, there is no further indication ; and it would be necessary to wait until it were renewed, as there would be no index to show which number had called. Evidently then, when subscriber No. 5 calls, there must be some visible and continuing sign made at the office, showing clearly that No. 5 is waiting.

When a battery is used this is a simple matter, and when we speak of Edison's telephone we shall explain how it is accomplished ; but the Gower telephone has no battery, and if its simplicity is to be preserved it must dispense with it. If the use of the battery has some advantages, there are also some inconveniences. A battery increases the sound transmitted, and is said to simplify the signals. This may be true ; but on the other hand the battery involves expense, and whatever may be its form, is necessarily consumed so long as the current passes. If the subscriber should forget to turn his commutator, the battery is exhausted in a night, and on the morrow the apparatus fails to speak. If all this can be avoided so much the better. But the difficulty in question is a serious one, and we have to thank M. Ader for solving it by the exhibition of a visible sign showing the correspondent's call.

The visible sign may be the shifting or fall of some piece of the apparatus, or a change of colour. In every instance it is a movement which must be effected by the telephone. * But the instrument yields only vibrations, and it is these which must be transformed into movements. Fig. 9 will show how this is accomplished : A is the magnet of a telephone, and the wire proceeding from the line is wound on the bobbins BB. The vibrating plate of the telephone is reduced to the little strip R fixed against s. The white disc bearing the word *Répondez* (Answer) is the signal. In the position represented in the figure it is concealed ; but its weight tends to make it fall, and when it has done so it becomes visible through an opening made in the front of the case, which in the figure is removed in order to show the mechanism.

As here shown it is prevented from falling by a lever L to which its upper part is attached, and which is provided with a suspended hook which catches in a square hole, o, made

through the strip R, as shown in the right-hand figure. The shape of this little hook must be noticed. It will be seen at c that it has the form of a small triangle, making a sort of inclined plane drawn upwards by the weight of the disc, and is readily disengaged by a slight movement of the strip R. Of course, the signal is marked with the number of the subscriber with whose wire it communicates. Our subscriber No. 5, who has been waiting all this time, may now if he please make the call. He has only to blow into his apparatus, and then, in consequence of the comparatively powerful electric currents

FIG. 10.

which pass through the bobbins B, the strip R is thrown into vibrations; and at each vibration it leaves the hook c, and this is enabled to rise a little at each movement. After a few vibrations it becomes completely free, and the disc, no longer kept back, falls and shows itself at the window, indicating that No. 5 has called and is waiting.

Is not all this remarkably ingenious? Observe, the disc is not shown unless the trumpet be used; it does not fall by merely speaking, for the vibrations then produced are insufficient. This indicates the difference between the molecular vibrations derived from articulate speech, and the more perceptible vibrations arising from musical sounds.

The apparatus, however, is not now constructed exactly as

shown in the figure, for that arrangement is found to be too sensitive to slight shocks. The hook *c*, instead of having the arrangement shown in the figure referred to above, and shown also on the left-hand side of Fig. 10, has in reality the arrangement represented by the right-hand diagram of that figure. It is released when the vibrations of the strip *R* have in a manner driven it clear. *R* is here inclined, and there are other modifications ; as for instance, the magnet has only one bobbin, the other end instead of a bobbin carrying the strip *R* itself, so that the vibrations of the latter are amplified. As thus

FIG. 11.

arranged the apparatus works very well. It is somewhat delicate, perhaps, but it would no doubt be impossible to adopt anything firmer, on account of the small amplitude of the movements which have to be employed. An electric bell can be added to the apparatus when required, so that, if the clerk has to leave his office, he puts his signals into a local circuit with the bell. As soon as any one of the discs falls the bell is set going, and the operator is made aware of the call, and comes to see who requires to communicate. In practice these signals are arranged by sixes in one box, which has the general form represented in Fig. 11.

Thus, thanks to M. Ader's elegant apparatus, subscriber No. 5 will not have to wait indefinitely with his telephone at his ear. A clerk will hasten to answer him. But it is not with the clerk that No. 5 wishes to converse, but with another subscriber who is known to him, and whose number is 9, say. This correspondent must be advised and placed in communication with No. 5. This operation so easily stated is not so easy to accomplish, and the difficulties attending it are greater in proportion as the subscribers are more numerous.

The following is the manner of overcoming those difficulties

which has been adopted by the *Compagnie Générale des Téléphones*. In the first place the subscribers are divided into groups of not more than thirty each, and those who are most frequently in communication with each other are arranged to belong to the same group. To each of the groups a special

FIG. 12.

clerk is appointed. This arrangement is obviously an advantage, though it may appear to entail some cost. The American systems have *switchmen*, who attend to many lines: a plan which is no doubt more economical, but, on the other hand, increases the liability of mistakes being made.

The clerk in charge of each group has in front of him a system of Swiss commutator like that represented in Fig. 12,

where however it is supposed that only ten correspondents belong to the group, whereas in reality there are twenty or thirty. The upper part of the commutator is a box containing as many Ader signals as there are lines, and marked by the proper numbers. The circles in the figure are the little windows at which the call-disc makes its appearance. Above is the electric bell, which can at will be connected with the signal detent, and made to establish a short circuit with a local battery. This is, when required, effected by means of the commutator 1. But now we suppose the clerk to be present, and to see the signal made by subscriber No. 5. Then he uses the lower part of the system, namely the Swiss commutator. It will be seen that each subscriber is there represented by a band of metal bearing his number. Behind the wooden strip that supports these vertical bands at the front, are other horizontal bands (shaded lightly in the figure), crossing the former without touching them. But it is only necessary to insert a metallic peg in one of the holes in the front bands, to connect it with one of the hinder bands. Each band is provided with a peg. At present they are all at the bottom of the frame in the band marked *terre* (earth). The clerk takes out the peg in No. 5, and raising it a stage thrusts it in at the level marked *tél* (telephone). He is then in communication with No. 5, and taking his own instrument which is seen on the right, he asks, "To which number, sir, do you wish to speak?" "To No. 9," replies the subscriber. "All right, sir, I will inform him." When the clerk has removed No. 5's signal, he then shifts the peg of the band 9 from *terre* to *tél*, precisely as for No. 5. The clerk is then in communication with the second subscriber, and calls by sounding his signal.

If No. 9 be not too far from his telephone, this call will suffice; otherwise, if there be much noise on his premises, he must be supplied with an Ader signal, provided with a bell apparatus. But in nearly all cases the telephonic signal is sufficient. By one means or the other, notice is given to the subscriber No. 9, who answers, "Who calls me?" The clerk replies, "No. 5 asks for you; I am placing you in communication with him." Then, going back to No. 5, he says to him, "No. 9 has replied; you are in communication." Then,

FIG. 13.—Central Telephone Office.

taking the two pegs of Nos. 5 and 9 he thrusts them in on the same horizontal line, the first one for example. From that moment, 5 and 9 converse together, and the central office has no communication with them. Observe that the signals of Nos. 5 and 9 are removed from the call frame, and that as speech is not sufficient to set them in action, they remain so long as only speech is carried on. But when Nos. 5 and 9 have done, each blows into his instrument and their signals re-appear, which shows the clerk that their lines are no longer required. He takes out the pegs and sets them again in the line "*terre*," and the operation is at an end.

It will be seen why the commutator has across all its vertical lines several horizontal lines. Suppose, for instance, that during the conversation between 5 and 9, 3 and 7 also wish to converse together. The pegs of Nos. 5 and 9 are in the first horizontal line, and if those of 3 and 7 were also put there, the four telephones would be united and endless confusion would be the result. But by placing 3 and 7 on another line, as for instance on the second, this inconvenience would be obviated. No mistake can be made, as each line with a peg in it is engaged.

All this description supposes that the correspondents belong to the same group. If they do not, the operation, although a little more complicated, is yet similar. Let us suppose that subscriber 5 calls and says that he wishes to speak with No. 83. The clerk has not this number in his group, A, which goes only as far as No. 30; the second group, B, ends with No. 60. It is therefore to the third group, C, that the required number belongs. The clerk of the first group answers that he is going to cause No. 83 to be called; then he chooses a free line amongst the horizontal lines of his communicator placed near the bottom. These lines are not shown in our figure, but their position is between the lines marked respectively D and *tel*. In the line so chosen, which we shall suppose to be marked "6," he places the peg. He then writes this memorandum for the clerk attached to group C: Subscriber No. 5, group A, line 6, wishes to speak to subscriber No. 83, group C. The clerk attached to the C group, on receiving this speaks to No. 83, and after receiving his reply places his peg on the horizontal band 6, and then he sends the memo-

Fig. 14.—Telephone Exchange, New York.

random on to a third clerk to attend to a particular commutator called "the great commutator." This third clerk establishes a connection between groups A and C, through line 6, and the two subscribers are able to converse together. When they have finished they give the signal, and all the pegs are taken out and replaced in the line "terre."

Fig. 13 is a general view of the central office, containing

FIG. 15.

these apparatus, showing the boxes in which the clerk in charge of each group is placed, and the apparatus under his control. At the further end of the apartment is the "great commutator."

In April 1880, there were in Paris fifty lines in use, and the *Compagnie Générale des Téléphones* was about to establish systems in other great centres. At that time the use in France of telephonic communication was confined to Paris; while at the same period there were in the United States eighty-five cities making use of the telephone. At Chicago there were

3,000 subscribers, at Philadelphia 600, at Cincinnati 600, and an ever-increasing number in New York; the total number of subscribers to telephonic offices in America exceeding 70,000.

The telephonic service at New York is managed as follows :—
If we enter the principal hall of the Merchants' Telephone

FIG. 16.

Exchange at 198, Broadway, we see a number of *switchmen* (see Fig. 14) employed in establishing communication between the subscribers. At one place a switchman is listening to a subscriber who has called (Fig. 15), at another the *employé* is removing a call-signal (Fig. 17). The subscriber has, at his place in the city, his *office telephone* (Fig. 16), such being placed in a great many places of business. This form is very convenient, for the mouth-piece on the left side may be spoken into

while you listen by applying to your ear the instrument shown suspended to the desk ; at the same time notes may be taken with the hand that remains free.

Before we follow the series of operations forming a complete call, let us examine the system of telephones used in the Broadway office. This system belongs to the class of battery telephones, and thus allows these batteries to be utilized for the

FIG. 17.

calls to the subscribers by means of ordinary electric bells, such as represented on the desk of the office telephone, Fig. 16.

The transmitter is Edison's carbon telephone, which is based on the variations of electrical resistance produced by variations of pressure caused by the plate when the mouth-piece is spoken into. Thus, variations in the intensity of the current are produced according to the inflexions of the voice, the vibratory movements of which are faithfully reproduced. The circuit is formed by the battery (two bichromate of potash cells), the transmitter, and the primary wire of a small Ruhmkorff coil

without an interrupter. The line and the receiver of the distant station are connected with the secondary wire of the coil, the other end of which communicates with the receiver of the station and with the earth. It follows from this arrangement that the line currents are currents induced by the variations of intensity in the current which passes through the primary wire of the coil. The effect of this arrangement is to transform into tension currents the vibratory currents of the transmitter, and to make them less sensitive to the variations of the line resistance. It also renders the fittings of the apparatus more simple, and dispenses with a portion of the commutators, the manipulation of which might cause errors.

The receiver is a Phelps telephone, similar to the Bell telephone, but with its magnet bent into the form of a ring, so that it is very easily handled.

In the position of rest, or of waiting, the telephone is suspended on its hook, and in this position it causes a piece to turn, forming a commutator, which cuts off all the telephonic part of the circuit, and puts the electric bell into the circuit. Everything is then ready for a call.

In taking up the telephone by the hand, the piece by again turning automatically resets all the connections with the telephone.

The telephones of the clerks of the central station, transmitting and receiving, are similar to those of the subscribers ; but in order to facilitate the manipulation of these apparatus, the transmitter and the receiver are mounted on the same support, which is a little curved, so that it may be used as a handle, as shown in Fig. 15, while at the same time it forms the magnet of the receiver.

We are now able to follow the whole series of the operations. Let us suppose that the subscriber No. 411, whom we may call Brown, wishes to correspond with No. 131, whose name, say, is Jones. Brown begins by several times pressing a small stud placed at the right-hand side of his desk.

While the telephone is hanging, the result is that the current of Brown's battery traverses the line and a small electro-magnet at the central station. This electro-magnet when thus excited allows a little door to open, and the slight noise it makes in doing so suffices to attract the attention of the

clerk, who then sees the number 411 displayed. The clerk then puts himself into communication with Brown, beginning with the queer but convenient expression, "Hallo! hallo!"

Brown asks the clerk to put him into communication with No. 131. If this number is disengaged at the time, the clerk, presses a stud after having connected the wire of No. 131 with that stud. Jones's bell then rings, and Jones, hearing it, touches in his turn his bell-stud, which causes the little door corresponding with his number to drop at the central station. When a direct line of communication has been established between the two horizontal bars corresponding with the line-wires of Brown and Jones, the two may converse in secret if the clerk withdraws his telephone. Should a third subscriber, No. 42, who may be designated Robinson, wish to correspond with Jones while Jones and Brown are still conversing together, the clerk is able to take part in the conversation of the two last-named, just as a servant would in announcing a visitor.

The person called by the clerk may then answer immediately, or cause Robinson to be made aware of the time when he will be at his service. If there be no objection to the conversation being carried on between Brown, Jones, and Robinson, a simultaneous communication between the three may be established by directing the clerk accordingly. The arrangement is equivalent to the "Come in" of every-day life.

Telephonic communications, carried on in the manner we have just described in each of the two systems, prove of very great utility. They annul distance and bring the correspondents into each other's presence as it were, so that a conversation can be carried on as if the interlocutors were in one room.

Let us point out some very ingenious arrangements in the details. When the conversation between Brown and Jones is finished, each of them hangs his telephone on its hook, and touches his stud. The number of each thereupon again appears at the central station, and the clerk there is made aware of the termination of the conversation. He closes the little doors, removes the connection between Brown and Jones, and all is ready for a new call.

In stations where there are 500 or 600 subscribers, the

numbers are arranged in frames, each containing from 50 to 100 ; and special commutators are used for communicating between the several series.

At New York the central station effects no fewer than 6,000 communications daily, and this done to the entire satisfaction of the subscribers. The telephone has become for them as indispensable as the omnibuses and the tramways are for us.

Every month a list of the subscribers is distributed, arranged alphabetically, and by professions. The Philadelphia lists are printed like books, and are provided even with eyelet holes for hanging them below the telephone. At Chicago the list now constitutes a small volume.

The American District Telegraph Company has greatly extended its service, and in its address-book is the following announcement :—

Notice to Subscribers.

A servant in livery will be at your door three minutes after your call, to distribute your notes, invitations, circulars, carry small parcels, &c., . . . to accompany a lady or a child to any place, or to bring them back. He will bring your children home from school ; or during a storm will carry umbrellas, &c., to church or elsewhere, when necessary ; he will fetch a doctor, a nurse, medicine, a friend, a coach, &c., at any hour.

Have we not here the practical spirit carried out to the uttermost ? It is, of course, quite possible to accomplish what is here announced, for the district telegraphs are so spread throughout the whole city, that you are never more than five minutes' distance from an office. The same company has also instituted a service for supervising night-watchmen, a service which will be talked about in France perhaps twenty years hence. In the meantime let us avail ourselves of the telephonic communications which are each day becoming a more pressing necessity. They are rapidly taking their place in our daily life, and everything leads us to believe that their number will quickly increase.

CHAPTER III.

PNEUMATIC TELEGRAPHY.

History—Arrangement of the Tubes—Carriers—Apparatus and Engines for condensing and exhausting air—Utilizing the compressed air—Motion of the Carriers—Accidents—Continuance of the service during derangements—Systems of Tubes in Paris and Berlin—Bell for compressed air.

THE first sending of despatches by air pressure was, according to the Abbé Moigno, accomplished by Ador in 1852, at the Parc de Monceau. In 1854, M. Galy Cazalat in France, and Mr. L. Clark in England, took out patents for a system of forwarding letters in tin cases. About the same time, Mr. Clark fixed in the central telegraphic office in London (Telegraph Street), some short lengths of tube in which he caused the cases to move in either direction by exhausting the air.

In 1863, Mr. C. F. Varley completed this arrangement, by making use of compressed air for sending the cases in one direction, and of rarefied air for sending them in the other direction. Mr. Varley also contrived various kinds of valves which we shall presently describe.

In 1865, Messrs. Siemens and Halske laid down a peculiar arrangement of pneumatic tubes between the telegraph office and the Exchange at Berlin. Two tubes were placed side by side and connected together at one end so as to form a complete circuit. The two free extremities terminating at the telegraph office were connected with two reservoirs, one of compressed, and the other of rarefied air, furnished by the continuous operation of a double-action piston, driven by a steam engine. In this way a current of air constantly passed through the tubes in the same direction; and while one of these tubes served to convey the cases in one direction, the other conveyed them in the opposite direction. The length of the current was

at that time 2,022 yards, but since 1865 a second circuit having a length of 4,064 yards has come into use. The offices it connects are, in addition to the Central Telegraph Office, those of the Potsdamer Thor and the Brandenburger Thor.

The same system was, with some modification of the details, applied in London in 1870. As pneumatic tubes on Clark's system, modified by Varley, as well as some on Siemens' system, are now working in England, we shall further on give a detailed description of them.

At Paris, pneumatic tubes came into use in March, 1867. The apparatus erected in the office in the Rue Boissy-d'Anglas was composed of three iron-plate vessels ; one for water, of the capacity of 1,540 gallons, and two for air, holding 240 cubic feet. Communications could be established at will between these three vessels, and the tube through which the messages were sent was joined with one of the air-vessels through a pipe provided with a stop-cock. With the water vessel were connected a pipe conveying the town water, and another pipe for discharge. By admitting water into one of the vessels until it was completely filled, the volume of air contained in the three vessels was reduced from 6,580 cubic feet to 4,134 cubic feet, and the internal pressure became therefore equal to 1.6 atmospheres. Compressed air propelled the carriers in one direction, and motion in the other direction was caused by allowing the water filling one of the vessels to flow away, so as to produce a partial vacuum. The system was very simple in its arrangements ; but it could only be used where a sufficient and cheap supply of water was at hand. In the course of the year 1872, however, the French government substituted steam-engines for these air-compressing water vessels.

In London the pneumatic tubes all go to the Central Telegraph Station where the steam-engines are placed. Mr. Clark's original system now remains only in one direction, between two rooms in the central offices, namely, the Provincial Gallery, and the Intelligence Department. It is thus arranged :—

A lead pipe of $\frac{3}{4}$ -in. diameter connects these two offices. The one or the other end of this tube can at pleasure be put in communication with a vacuous vessel. When one of the offices desires to send a carrier, the latter is placed in the tube, and a signal is made to the other office to open the stop-cock

connected with the vacuum. The atmospheric pressure then moves the carrier forward. The operations for moving it in the other direction are just the same. The opening of the stop-cock is asked for by a whistle at the end of a tube of $\frac{1}{2}$ -inch diameter, which extends from one office to the other, each being provided with such a tube.

Clark's system as modified by Varley was applied in sixteen directions, but one of these is not in use. Seven of the tubes are provided with valves invented by Mr. Varley, the others have valves of a similar arrangement made by Mr. Wilmot. Except this difference, the arrangement is the same in both cases; the tubes and carriers are identical, and the same engines are used for all the lines.

A single tube is laid between the central station and each of the offices connected with it (unless the traffic be so great as to require the addition of a second apparatus similar to the first). The carriers containing the telegrams that are to be delivered are forwarded from the central to the distant office by means of exhaustion effected at the latter. The transmitting and receiving valves are situated at the central office only. The tubes are made of lead; they are $1\frac{1}{2}$ inches in diameter in some lines, and $2\frac{1}{4}$ inches in others. Their thickness is $\frac{1}{5}$ inch in the first case, and $\frac{1}{4}$ inch in the second. They are in 6-yard lengths. The joints by which the lengths are connected together have to be made with great care, in order that there may be no unevenness in the inside. For this purpose a steel mandrel, previously warmed, is fitted into the ends of the two tubes. The mandrel has exactly the diameter of the opening, and when the joint has been soldered round it, is drawn out by means of an attached chain.

Before the tubes are joined together, they are brought to the required diameter by causing a steel mandrel with a rounded front edge to traverse them. This mandrel is fastened to a chain wound round a barrel. Previous to this operation the diameter of the tubes is slightly less than that of the mandrel. When they have thus been adjusted, they are carried to the places where they are to be fixed, protected by wooden cases lest they should lose their shape.

The tubes are buried in the ground to the depth of about 2 feet, and are protected by cast-iron covering pipes of sufficient

diameter to hold their soldered joints. The iron is $\frac{1}{5}$ inch thick, and the pipes have their socket joints filled in with hemp and covered with lead. The smallest radius usually given to the bends of the pipe is 8 feet. For curves the cast-iron pipes are made in two portions, and the upper one is fixed by means of bolts passing through collars, after the leaden tubes have been laid.

There is no water reservoir in the course of the tube; the little moisture produced by the compressed air is absorbed by the felt covering of the carriers. Collecting wells, like those represented in Fig. 26, are, however, placed at certain intervals.

The carriers (Fig. 18) are made of gutta-percha: they are $\frac{1}{5}$ inch thick and $5\frac{3}{4}$ inches long; the external diameter of the

FIG. 18.

gutta-percha cylinder is $1\frac{3}{4}$ inches for tubes of $2\frac{1}{4}$ inches diameter. The front part of the carrier is made thickest, in order to resist the shocks it undergoes at the end of its journeys. An elastic band $\frac{1}{2}$ inch wide surrounds the carrier in the direction of its length, and partly covers the open end, to prevent the telegrams from falling out in transit. A wrapping of common felt covering the whole prevents the gutta-percha from becoming heated and softened by direct friction on the interior of the tube. This covering is funnel-shaped at the open end, so that the felt may be forced by the pressure of the air against the inside of the tube, and thus completely close it. A number of felt discs attached to the front end of the carrier also aid in making it into a piston, and in protecting the gutta-percha from the effects of shocks.

These carriers last a long time. After two months' use the felt covering and the elastic band are renewed. The cost of doing this is 2*d.* for the felt, 2*d.* for the elastic, and 2*d.* for the labour.

We shall now describe the peculiar valves that are used for despatching and receiving the carriers.

Varley's Valves.—These valves are represented in Figs. 19, 20, and 21, and they act in the following manner :—

When a carrier has to be received from the communicating office, the stud *B*, Fig. 21, is pressed : a valve in the box *V*, is thus opened and the vacuum vessel is thus connected with the cylinders *C* and *D*, through the pipe *h* and *j* ; by the effect of atmospheric pressure, the piston of the cylinder is lowered and completely closes the cover of the box *E*. This cover is formed of a plate of glass mounted in a copper frame provided with india-rubber round its edges. At the same time, the piston of the cylinder *D* is raised and kept up at its highest position by the stop *a* on its rod, which rests on the projection of the piece *t*, oscillating about its upper end, and it is pressed by a steel spring against the piston-rod. The movement of this rod opens a valve that puts the cylinder *H* in communication with the vacuum reservoir. The air in the box *E*

FIG. 19.

is thereupon rarefied, and so is that in the underground tube which is connected with the box *E* by the pipes. The carrier, which has previously been placed in the extremity of this pipe, is then drawn towards the box *E*, and on its entry therein, severs the communication with the vacuum reservoir in the manner following :—

By striking against the india-rubber disc *r*, shown by dotted lines, it opens, by its impetus, a valve by which *E* and *I* are put into communication ; exhaustion then takes place in the box *I* and in the cylinder *K*, which are connected by the pipe *g* ; the piston of this cylinder is pushed back, and its rod, acting on the hinged lever *p*, causes the rod *q* to slide and

separate the piece *t* from the stop *a*. As the exhaustion no longer continues above the piston of the cylinder *D*, that piston falls by its own weight, and closes the communication with the vacuum reservoir. At the same time, the clack-valve *v* having been opened by the movement of the lever *p*, the air enters the cylinder *H* and the underground pipe; at this instant the cover of the box *E*, which was kept closed by the atmospheric pressure, falls by its own weight. The apparatus is thus brought to its usual condition, and is ready to act again.

FIG. 20.

In despatching a carrier it is placed in the tube *s*, and then the stud *B* is pressed; the compressed air then enters the cylinder *L*, Fig. 19, by the tube *l* and urges the piston forward; this closes the valve *m*, which in that position stops the extremity of the subterranean tube. When the piston has gone beyond the opening *b* of the pipe *d*, the compressed air rushes through *d* into the cylinder *N*, the piston of this cylinder being thereby pushed to the bottom of its course (Figs. 20 and 21) is maintained in that position in a manner similar to that which we have indicated above for the cylinder *D*: the compressed air rushes into the cylinder *H* and the underground tube, and the carrier is driven to the extremity of the latter. On the arrival of the carrier, the

clerk appointed for that purpose signals to the central office by means of a common electric bell. On receiving this signal, the operator at the central office presses the stud B'; the vacuum reservoir is thus put into communication with the cylinders L and K through the pipes *m* and *g*, the piston of the cylinder L opens the valve M, and the piston of the cylinder K, by disengaging, as we have seen, the piston-rod of the cylinder N, closes the valve admitting the compressed air, and at the same time opens the valve *v*. The atmospheric pressure is then re-established in the underground tube.

FIG. 21.

This apparatus works with much regularity, but it is complicated, and its cost amounts to £60. Mr. Wilmot has simplified the arrangement of the valves. Apparatus of his construction is working on nearly all the new lines in London. The valves are represented in Figs. 22 and 23, where T is the pipe forming the prolongation of the underground tube.

To receive a carrier the lower end of the tube is closed by raising the hinged clack-valve C, which is covered with india-rubber; then the cock *v* is turned, by which communication is established between the vacuum reservoir, the tube T, and pipe S; the latter is exhausted and the clack-valve thus being kept close by the atmospheric pressure, the carrier is drawn

forwards. Its impetus causes it to open the clack-door *c*, and its velocity having thus been destroyed, it is drawn against the opening *o* of the tube *s*. As soon as the person appointed for that purpose sees the door *c* fall, he closes the cock *v*, and then the carrier, being no longer kept up by the external pressure, drops out of the tube *t* by its own weight.

A carrier is sent in the manner following:—It is placed in the tube *t*, and the slide formed by the rods *g* and the cross-piece *d* is drawn out by the handle *m*; the cross-piece is thus

FIG. 22.

FIG. 23.

brought against the stop *f* fixed on the rod *b* and brings this with it. The sliding door *K* attached to *b* then advances and closes the end of the tube *T*. As soon as this is done, the inclined plane *h* fixed to the rods *g* meets the roller *j* and pushing against it, opens a valve placed within the cylinder *L* and thus connects the reservoir of compressed air with the pipes *M* and *T*. The carrier is thereupon sent through the subterranean tube, and when its arrival has been announced by the ringing of the electric bell, the slide is pushed into its normal position.

If the rod *b* were invariably connected with the cross-piece *d*, a certain effort would be required to push back the slide, on account of the friction produced by the excess of pressure on the upper surface of the door *K*. To obviate this inconvenience, the rod *b* is made to slide in the cross-

piece *d* within the limits given by the stops *f* and *l*. The stop *f* acts in the way we have already explained ; the stop *l* comes into use when the slide is pushed in, the rods *g*, and the cross-piece *d* first slide alone, while the rod *b* remains stationary ; during this movement, the inclined plane *h* leaves the roller *j*, and the compressed air ceases to enter the tube *T* ; then the cross-piece *d* meets the stop *l*, and the rod *b* carries the slide-door easily along with it.

Most of the pieces forming the valves are of brass, and are fixed against two stout planks (Figs. 19, 20 and 21), one of which is vertical, and the other horizontal. The latter forms a table on which to place the carriers about to be sent, and to receive those that arrive.

In all the terminal offices the arrangement is the same, whatever may be the system of valves employed. The end of the subterranean pipe opens into a cubical wooden box measuring 14 inches each way. The front of this is provided with a door having a glass pane, and turning on two hinges fixed on the upper horizontal edge, the door opening towards the inside.

This box rests on another of larger dimensions lined in the inside with lead. A leaden pipe, communicating with the town drains, enters the lower part of this box. A cast-iron grating placed in the panel separating the two boxes allows the air to pass from one to the other, and prevents the carriers from falling into the lower receptacle.

When a carrier has to be sent, it is placed in one end of the tube, and the central office is signalled to exhaust.

When a carrier is received, the air it drives before it closes the door of the box and escapes through the grating without inconvenience to the operator.

The communication with the sewers is necessary to carry away the water with which the tubes may have to be flushed, in order to drive out carriers that have accidentally stuck. These cases are extremely rare ; but special arrangements have nevertheless to be made to get rid of such obstacles. For this purpose, a pipe brings the town water into the room containing the apparatus at the central office. When the tube is blocked with a carrier, it is filled with water, and the compressed air is then made to act upon the water at the highest obtainable pressure.

As the pneumatic tubes go to the upper stories, the pressure of the column of water is added to that of the compressed air, and this method is invariably efficacious.

We have said that the signals required for working the tubes are made by electric bells. There is nothing remarkable about these bells, except that, instead of a continuous tingling, they give only a single blow of the hammer each time a current is sent. At every repetition of the signal, a disc falls behind an opening in the case, and remains in that position until it is raised up again by hand.

Reservoirs made of iron plates are used for containing compressed or rarefied air, so that no change of pressure is perceptible when a carrier is sent.

For compressed air, the dimensions of these reservoirs are as follows :—1. A cylindrical reservoir, 8 feet 6 inches diameter, 11 feet 2 inches high, holding 630 cubic feet. 2. A reservoir of the same shape and section, but only 9 cubic feet high ; its capacity is 440 cubic feet.

The total capacity is 1,070 cubic feet.

These reservoirs are fixed and are provided with a stop-cock at the bottom, for emptying out the water resulting from the compression. This is done every night.

The reservoirs for rarefied air are also two in number : one has a capacity for 630 cubic feet, and the other of 160 cubic feet, the total being 790 cubic feet.

The steam-engine first erected for working the tubes of Mr. Clark's system is a horizontal expansion engine, of 28 horse-power. The diameter of the cylinder is $16\frac{1}{2}$ inches, and the stroke 2 feet 6 inches, the expansion begins at two-thirds of the stroke, and the maximum pressure is 40 lbs. per square inch, the pressure in the condenser being 7 lbs. per square inch, and the number of revolutions 48 per minute. The theoretical horse-power is 40, but the indicated horse-power is only 25·20.

The blowing cylinder is in a line with the steam cylinder, and is double acting, with ordinary valves. The air is, therefore, compressed on one side of the piston and rarefied on the other. This simplifies the mechanism, as only one cylinder is required ; but the useful effect is diminished. For when the piston returns, after having reached the end of its stroke, the

compressed air contained in the part beyond the working space expands, and the piston has to move a certain distance before that air is brought to the pressure corresponding to that of the vacuum reservoir. The work consumed in this expansion is in part lost, if compared with that which would be required with two cylinders, one for compression, and the other for rarefaction.

A small 4 horse-power engine, driven by the town-water supply, is placed near the steam-engine, and is used in case the tubes have, from any unusual circumstance, to be worked during the night.

It is formed of two horizontal cylinders acting on a horizontal shaft, provided with two fly-wheels, and transmitting motion to the piston of the compressing cylinder by means of a connecting rod. Each cylinder is fitted with a slide valve, and the pressure of the water is 36 lbs. on the square inch.

The water supply of the city cannot be advantageously used in London, on account of the high price charged for it, amounting to 1s. for 164 cubic feet. The head being 84 feet, the theoretical worth of a cubic foot is 5,250 foot-lbs. To thus obtain the work of an engine of 40 horse-power, would require 15,000 cubic feet of water per hour, which at $\frac{1}{136}d.$ per cubic foot involves an expense of £4 11s. 5d. per hour.

Now, a steam-engine of 40 horse-power, of the construction least favourable for economy, that is to say, an engine neither working expansively nor condensing, would only consume per hour about 100 lbs. of coal, the value of which is 1s. 6d. The costs of maintenance and labour must be added to that of the coal, but these are insignificant compared with the expense incurred when water is used.

At the Central Office in London, the boilers are placed in cellars close to the engines. Two of them have internal fire-places ; their diameter is 5 feet, and their total length, 16 feet ; the fire-bars being 5 feet long. The third boiler is tubular and vertical, 6 feet in diameter and 7 feet high. The maximum pressure of the steam is 40 lbs. per square inch.

The Messrs. Siemens have successfully employed an apparatus for exhaustion, which is based on the same principle as the exhaust pipe by which the draught is maintained in locomotives. A steam-jet, carried into a suitably-shaped pipe

communicating with the underground tube, draws out the air and tends to produce a vacuum. The useful effect depends upon the section of the opening from which the steam issues, on the length and section of the tube in which the air and steam are mixed, and upon the pressure of the latter. Messrs. Siemens have found that by this aspirator a vacuum corresponding with 23 inches of mercury can be produced with less expenditure of steam than with a piston machine. According to them the first cost and the working expenses are only one-twentieth of those of an ordinary steam-engine. Besides this advantage, the apparatus is remarkable for its simplicity, the small space it occupies, and the facility with which it can be worked and kept in order.

FIG. 24.

We shall now describe Messrs. Siemens' system of tubes :—

As we have already mentioned, there are, between the terminal offices to be connected, two tubes forming a complete circuit (Fig. 24).

Intermediate offices may be interposed along the circuit. A current of air is constantly circulating through the tubes in the direction shown by the arrows. To send a carrier from any point of the line, it is only necessary to place it in the tube. This is done by valves of a particular kind (which we shall presently describe), and the office for which the carrier is intended having been warned by an electric signal, stops the carrier in its passage by means of these same valves.

If none of the intermediate offices intercepted the passage of a carrier sent from the Central Office, the carrier would return again to that office after having traversed the whole line.

Instead of specially warning each office when a carrier is sent to it, the precise time at which each of them should have its valve in the receiving position, might be fixed beforehand.

This arrangement would have to be so made that there should not be any delay, on account either of the insufficient number of carriers, or of the inopportune intrusion into the circuit of carriers from any particular office.

Several similar circuits, each comprising a larger or smaller number of intermediate offices, may have their terminations at the office provided with the machinery. The power of the machines will of course depend, other things being equal, upon the length of the circuits they supply.

One of the extremities of each circuit is in permanent communication with a reservoir of compressed air, and the other with a reservoir of rarefied air. The speed of transmission by

FIG. 25.

this arrangement is evidently greater than that which would be obtained if the compressed or the rarefied air were used alone.

It should be observed that the internal pressure of the air varies throughout the tube. When no carrier is passing, this pressure, at its maximum near the reservoir of compressed air, continues to decrease as the distance increases, diminishes to the pressure of the external air at a certain point, and beyond that continues to fall lower as the vacuum reservoir is approached. The position of the point at which the pressure is that of the external air varies with the relative powers of the pressure and the vacuum, and is modified by the windings of the tube as by an effect of friction. In consequence of this, the velocity of the air-current varies at different places. For as the same quantity of air in weight must during a given

time pass by every section of the tube, the volumes, and consequently the velocities, are in inverse proportion to the densities, in accordance with Mariotte's law.

We have said that the same reservoir and the same machines are used for tubes on Siemens' system and for those on Clark's system. As an account of these has been given above, we have only to add, that Messrs. Siemens' aspirator having been finally adopted for a part of the system, a set of the apparatus has been fitted up at each of the extreme offices, and the circuit has been divided into separate and parallel lines, traversed by air-currents in opposite directions, produced

FIG. 26.

by exhaustion only ; the use of compressed air having been entirely dispensed with.

The pipes forming the conveying tube are made of wrought-iron. They are 3 inches in internal diameter, $\frac{1}{8}$ inch thick, and 18 feet 6 inches long. They are bored out internally. The junctions are made by means of cast-iron sockets with their internal cylindrical portion bored so that the ends of the two tubes may exactly fit one against the other. The connection is completed by a packing of hemp and lead. The direction is changed by means of curved tubes having a minimum radius of 12 feet.

The pipes are buried in the ground to a depth of about 1 foot. These are laid inclining towards wells placed at intervals,

and intended to gather the water that condenses in the pipes. These wells are formed of a cast-iron box (Fig. 26) terminated by a pipe of the same diameter as the tube. A pipe, closed by a screw at the upper part, communicates between the well and a cast-iron box placed on the level of the pavement, and by this pipe the water can be removed when required.

The carriers are similar to those used with Clark's tubes, but differ by their greater size, and by having a gutta-percha cover, kept in its place by an elastic band. A second covering of felt with a funnel-shaped ending is also added at the extremity of the carrier.

FIG. 27.

The receiving and transmitting valves are represented in Figs. 27, 28, 29, and 30. The valve is formed by two lengths of tube, T and R, of the same diameter as the conveying tube, fitted on a frame that revolves on the axis A. One or the other of these lengths of tube is thrown into the circuit according as it is required to transmit or to receive.

The tube T being open throughout its whole length, the carrier that has to be despatched is simply placed in it, and T is then brought into continuity with the circuit by pulling the handle *p*; the air-current bears off the carrier the moment T comes into the position shown by the dotted lines in Fig. 29.

Figs. 29 and 30 show the apparatus in the receiving position. The tube R, then in the line of the conveying tube, is closed at one end by a disc pierced by small openings.

When the carrier comes into this tube it compresses the air contained in it, gradually losing thereby its own velocity; but the compressed air, being allowed to escape by the opening at the end of R, never acquires sufficient tension to drive the carrier back again. When the carrier reaches R the passage of the air-current through R is of course intercepted. But a side-pipe D allows the current to pass, and when the apparatus is brought into the receiving position, a valve *v* is made to open the tube D by the action of the moveable frame on the lever *l*. Similarly the moving of T into the circuit closes the valve *v*.

Two iron rods *q* limit the turning movement of the frame, and firmly connect the two fixed parts of the apparatus.

FIG. 28.

The touching surfaces of the fixed and moveable parts are flat, and they must be perfectly fitted to each other, so that no air shall pass between them. To render the movement easier a pedal may be added to the apparatus. The reception box R is for a portion of its length provided with a flat glass-cover which can be removed at pleasure in order to take out the carriers. The person in charge thus at once sees when a carrier arrives. He thereupon pulls the moveable frame towards him, and by pushing the handle *f* he causes a rod sliding in the guide-piece G to enter the tube R and expel the carrier.

When a carrier has to pass an office without being stopped, the clerk, having been warned by electric signal, places the frame in the same position as for transmission; and the carrier in passing touches a spring within the tube by which a bell is struck, so giving a signal that the carrier has passed.

It is one advantage of the Siemens' system that carriers may be sent from different points in the circuit.

The valves we have just described are those for the intermediate offices, in which each tube is used for reception in one direction and transmission in the other. At the central office the end of one tube serves only for the transmission, and that of the other for reception. At this office the length of tube on each moveable frame may then both be, as shown in Fig. 30, arranged for transmission or for reception. At the other extreme office a single complete valve is sufficient.

FIG. 29.

Messrs. Siemens' system has been used in Great Britain only from 1870. In London, the Central Office, the City, Charing-cross, Temple Bar and the Houses of Parliament are connected by it.

The air-current having opposite directions in the two tubes traversing each intermediate office, the arrangement may be compared to that of a railway with up and down lines.

This similarity has caused the telegraphic department to adopt for the signals required in working, Mr. Tyler's electrical apparatus, which is used on a great many railways in the United Kingdom, for safety in running the trains. The complete apparatus at the Central Office is connected with only one office, and consists of an electric bell, a case containing the electro-magnets, the two handles controlling the needles, and another handle for ringing the correspondent's electric bell. The upper needle is painted black, and the lower one red. A single line wire is sufficient for the transmission of the various signals. The black needle can be moved only by the correspondent; it marks signals received; the red needle repeats the signals sent, so that the operator himself sees them.

The armature of the electro-magnets is a piece of steel, or of

iron polarized by a magnet; the outer needle with which it is connected inclines to the right or left according as a positive or a negative current is sent, by touching one or the other of the handles. After each passage of a current, the needle regains its position by reason of the residuary magnetism, which is made as powerful as possible by the way in which the apparatus is constructed. This magnetism is sufficiently powerful to bring the needle to its normal position, if it be withdrawn by the hand from that position when the current has ceased to pass. The magnet that polarizes the armature is re-magnetized each time the current passes.

FIG. 30.

The advantages of this apparatus consist in the absence of adjustments, in the readiness with which the needles resume their normal position, in the preservation of the magnetism notwithstanding discharges of atmospheric electricity, and in the adherence of the needles opposite the poles of the electro-magnet, so that their indications are not affected by vibrations caused by the passage of trains. We may, however, point out that a single accidental current, such as would be occasioned by the approach of a thunder-cloud, or the touch of a telegraph wire, might cause the needles to assume a false position.

Every time a current is sent, the hammer of the electric bell strikes once.

The plan adopted in the despatch of carriers is that known as

the *block system*, by which the signal allowing a train to be sent cannot be given until notice has been received that the preceding train has reached the next post in advance. The signals received, which are shown by the upper or black needle, correspond with the despatches of trains, and the signals sent with the arrival of trains.

As each intermediate office has to correspond in two directions, two apparatus similar to that just described are necessary.

In order to be able to distinguish the direction from which the signals are sent, a "tam-tam," formed of a spiral rod of steel, is substituted for one of the bells (Fig. 31).

As we have already stated, London is the only town in England where tubes on the Messrs. Siemens' system have been used. Tubes on the systems of Messrs. Clark and Varley are laid in five other towns of the United Kingdom, namely, in Liverpool, Manchester, Glasgow, Birmingham and Dublin. The practical results show that, as regards speed, it is of advantage to use tubes of large diameter. They show also that, other things being equal, the speed is very different, according to the way in which the tubes are fitted up.

DERANGEMENTS.—*Stoppage of a carrier.*—Derangements may occur during the passage of a carrier, resulting from an accident to the conveying pipe, to the carrier, or to the apparatus at the offices.

Accidents to the machinery are quickly attended to, and the carriers can never stop long for that cause. If the repair requires some time, the corresponding office can by blowing into the tube send back the carriers to the office from which they came.

When anything has gone wrong with the carriers or with the line, sometimes the carriers may be urged on to their destination by increasing to the greatest possible extent the pressure of the air behind them. If this fails, the place at the obstacle must be dug out, and it is possible to determine with great precision the place at which the tube must be taken up. For this object, the difference of the pressure of the air in the reservoirs is observed when they are successively put into communication with lines of known length, and with the portion of the line out of order. The application of Mariotte's

law to the results of this experiment is capable of indicating, to thirty yards, the place where the tube must be taken up. Constant observation of the manometer enables the *employés* to make a sort of a practical graduation of the instrument, by

FIG. 31.

which they can follow the progress of the carriers, and by availing themselves of these indications they may infer the approximative position of an obstacle causing the sudden stoppage of a carrier.

M. Ch. Bontemps has applied the mode of experiment used by Regnault for the determination of the velocity of sound in

tubes, by noting very exactly the time taken by a sonorous undulation to traverse the tube as far as the obstacle.

The arrangement is shown in Fig. 32. A strip of slightly vulcanized india-rubber, *a, b*, is selected of about $\cdot 013$ inch in thickness when it is not stretched, and weighing about 4 grains per square inch. This membrane is stretched between pairs of metallic clips, connected by screws passing through the india-rubber. To the centre of the latter a small metal disc, *c*, is attached, and above this is a pointed screw, *d*. An electric cir-

FIG. 32.

cuit is formed when by the movement of the india-rubber, *c* and *d* come into contact.

This elastic membrane is placed over the open end of the tube, and the time of any rising up of the india-rubber is registered by means of electricity on a revolving cylinder. A sound-wave is produced in the tube by firing a pistol as shown in Fig. 32. This wave travels in the tube with the velocity of 1,074 feet per second, and striking the obstacle, is there reflected and returns in the opposite direction, causing a rising of the india-rubber on its arrival. Thus a mark is made on the cylinder. The membrane in its turn again reflects the wave towards the obstacle which sends it back anew, and a second mark is made on the cylinder. If the interval of time elapsing

between the appearance of these two marks can be estimated, it is easy to see that the distance between the membrane and the obstacle can be calculated.

The chronograph used by M. Bontemps has three tracing-points, acted upon by electro-magnets. The first is placed in the circuit which is formed by the alternate risings of the india-rubber.

The second tracing-point corresponds with an electric regulator, marking seconds of time on the cylinder.

The third tracing-point subdivides the space of the second, by means of the vibrations of an electric trembler.

The following is an example of a practical determination :

An obstacle is placed on the line, at a distance of 185 feet.

The trembler executes 33 oscillations per second.

The space on the strip of paper covering the cylinder between two consecutive marks of the india-rubber, corresponds with 11 oscillations.

The distance of the obstacle is calculated by the following formula :—

$$D = \frac{1}{2} \times 1074 \times \frac{1}{3} \frac{1}{3} = 179.$$

The approximation is therefore within 6 feet, and the obstacle can be reached by a single digging up of the tube.

In the current practice, this method is used without employing a registering chronograph and an india-rubber membrane. An ordinary chronometer measures the interval with sufficient accuracy. The return of the wave is made perceptible to the ear by the sound of a whistle, or to the eye by the sudden rising of a little water manometer fixed in the end of the tube.

VARIOUS ACCIDENTS.—We shall mention some other instances of derangements that have occurred.

1. *The piston forgotten.*—The air then acting directly on the carriers, finds its way between the covers and tends to separate them. The carriers become separated and reach the extremity of the tube one after the other, generally open and with the papers in disorder.

2. *A train of carriers forgotten.*—Though almost incredible, this certainly has happened. The reception signal had been given before the arrival of the train, and when another was sent it pushed the former one along and took its place. The

first was, on its arrival, supposed to be the second, and so on ; throughout part of the day the messages received were not those that were expected, until at length a comparison of memoranda indicated the nature of this singular accident.

3. *Carriers jammed together in opposite directions.*—Cases of this kind are similar to that described in the first example.

4. *Breakage of the piston.*—The collar is attached to the piston by means of a screw, which one day in winter having broken off, the train stopped, and became frozen up in the tube. It was a difficult matter to open the tube, for the line went under a bridge, and the river being frozen over, a floating scaffold could not be used. Several pistons were filled with hot water and were shot into the blocked part. They gradually removed the obstacle, and arrived at the end of the tube with the carriers and some lumps of ice. The screw still remained in the tube, but by sending on another piston very slowly, it also was pushed out.

5. *Accident to the tube.*—When the tube has been laid in trenches, the ground may be disturbed in laying gas or water pipes, or during the repairing of the pavement, and then the tube may receive a stroke from a pickaxe, which, though not penetrating it, may flatten it. This, of course, causes the stoppage of the carriers. Leakages of the air, which it might be expected would be frequent, are on the contrary unknown, even in cases where the tubes are exposed to the oscillations of the roadway of a bridge.

6. *Trials of new carriers.* It might be supposed that a piston fitted on its external surface with what is practically a brush would effectually carry out of the tube all the dust and mud it might contain. Unfortunately, whatever the brush carries away it takes to some lower or narrower part of the tube, when, after a few passages, it sticks itself so firmly that it is impossible to urge it on by pressure.

HOW THE SERVICE IS CARRIED ON DURING A DERANGEMENT.—While efforts are being made to send forward the stopped despatches, those that should follow must not be delayed, and the following rules are adopted in such cases:—

While trials and examinations are being made on the deranged portion of the line between any two offices, a service of carriages is established through the streets by which the

FIG. 33a.—Pneumatic Despatch Apparatus.

carriers are transported every quarter of an hour from one office to the other with the least possible loss of time. Of course, this is unnecessary when only a very short time is required for the removal of the obstruction.

If it should happen that the interruption is prolonged, the plan is adopted of sending the trains in either direction instead of circularly. In this case the compressed air apparatus will have to supply double the quantities necessary for the regular working. There is a loss of time in changing from one mode of working to the other; therefore when the interruption can be removed in less than four hours, the use of carriages over the interrupted section is preferred.

THE SYSTEM OF LINES IN PARIS.—M. Ch. Bontemps gives very precise details concerning the formation of the Paris system of lines. In 1866 a trial line connecting the Bourse (Exchange) and the Grand Hôtel was established and worked regularly with air compressed by the water supply of the city. The tubes were afterwards extended from the Grand Hôtel to the rue Boissy d'Anglas, then to the central station, rue de Grenelle-Saint-Germain. This office was afterwards joined to the Bourse by a second communication through the sub-offices of the rue des Saints-Pères, the Hôtel du Louvre (rue de Rivoli), the rue Jean-Jacques-Rousseau and so on to the Bourse. These works were finished in 1867.

Numerous branches have since been established, and the extensive works which are about to be commenced in order to complete the Paris system will be used by the postal service as well as by the telegraphic. Figs. 33*a* and 33*b* exhibit the general arrangement of the pneumatic apparatus in an important station.

Pneumatic tubes are not in use in the provincial towns of France, with the exception of Marseilles, where the central office, situated in the Place du Préfecture, has been connected with the Bourse by a tube 866 yards in length.

Together with the descriptions of the London and Paris systems, we shall give one of the Berlin system, so that our readers may be able to compare the pneumatic tube despatch services of the principal capitals in Europe.

Pneumatic tubes first came into use at Berlin on the 1st of December, 1876, and they were employed both for the postal

FIG. 336. — Pneumatic Despatch Apparatus.

and telegraphic departments. This mode of despatch has been called by the Germans "the tubular post."

We have already seen that the utility of the electric telegraph is, for short distances, relatively less than for great distances; for the absolute speed of the electric transmission is almost independent of the distance. For short distances, transmission by compressed air has, therefore, obvious advantages over electric transmission; because it allows many telegrams to be sent simultaneously, whilst with electric apparatus, the sending of telegrams, that is to say, the signs and words, can take place only in succession.

The number of offices in the tubular post system at Berlin, which was at first fifteen, now reaches twenty-three. These offices supply the most important parts of Berlin, and are connected with the central telegraph station and with each other by pneumatic tubes, the total length of which is twenty-four miles. The air, compressed and rarefied, is supplied by six sets of apparatus, in each of which two steam-engines work the several air-pumps. The velocity of transmission is about 1,086 yards per minute.

The cost of laying down the whole system at Berlin was 2,736,700 marks, including the purchase of land.

By means of the pneumatic tubes, letters and post-cards can be delivered one hour after having been posted, within the limits of the interior district. The tubular post is used also for distributing the telegrams arriving at Berlin, and those sent from the central office. It is also used for the despatch of packets and letters to the railway stations when the hour of departure of the trains is too near to allow of the ordinary modes of transport being used. Similarly the tubular post is used for communications arriving at Berlin.

The mean number of despatches in 1877 and 1878 was at the rate of 1,500,000 per annum.

The utility of the tubular post is so well recognised in Germany that the government is desirous not only of extending the system in Berlin, but of providing other towns with this advantageous mode of communication.

THE COMPRESSED AIR TELEGRAPH.—The pressure of air also supplies a means of making signals at short distances by means of very slight compressions through narrow tubes. We

give here a representation of one of Walcker's compressed-air bells, as an example of this kind of pneumatic apparatus. A tube *tt* transmits the pressure produced by the hand on an india-rubber ball *P*. The little bellows *A* is blown up, and its upper part *b* in rising lifts the lever attached to the bell *d e f* and causes the hammer *g* to strike the bell. When the india-rubber ball is $3\frac{1}{2}$ inches in diameter and the leaden conducting tube $\frac{1}{5}$ in. in diameter, the signals can be transmitted to a distance of 270 yards. This system may be used instead of the ordinary door-bell, as the tube has, in certain circumstances, distinct advantages over communications by bell-wires.

M. Guattari, of Berlin, has constructed a compressed-air telegraph perfectly resembling in its signals the Morse telegraph.

He fills a reservoir with compressed air by means of a hand-pump or by any other machine, and this reservoir is kept at a pressure suitable for producing the signals. By his apparatus, which was exhibited at Naples in 1870, very rapid and clear signals could be transmitted to a distance of eight miles. M. Guattari considers that his non-electrical telegraph offers great advantages for employment in mines, oil stores, &c. The apprehensions which have been entertained as to the inflammable power of sparks produced by the present electric telegraph apparatus are no doubt exaggerated; but, nevertheless, the pneumatic telegraph may be advantageously employed over distances not exceeding certain limits.

FIG. 34.

PART II.

THE ELECTRIC TELEGRAPH.

CHAPTER I.

HISTORY.

First attempts—Soemmering, Schilling, Gauss, and Weber—Their Telegraph—Steinheil—Introduction of Commercial Telegraphy into England by Messrs. Cooke and Wheatstone—Introduction of the Electric Telegraph into France by MM. Bréguet and Gounelle—European development—History of the Submarine Telegraph.

THE art of telegraphy by means of galvanism and electromagnetism is certainly one of the most interesting applications of science. This art has made such progress during the last fifty years that the present electric telegraph lines embrace the whole globe ; and the network is daily being extended so as to include even small places, and thus draw closer the ties that unite mankind.

It will be of interest to enquire who first worked a telegraph by means of an electric battery. This honour belongs solely to Baron Schilling, an officer in the Russian army, who constructed at St. Petersburg the first electro-magnetic telegraph, and we shall presently see how this led to the introduction of electric telegraphs into England.

But Soemmering had constructed in Germany a telegraph having signals produced by the action of a galvanic current in decomposing water. The date of this discovery must now be stated correctly, for authors are not in accord as to this date, and Steinheil himself, who lived in the same town as Soemmering, makes a mistake on this point. Besides, like Steinheil, Poppe and Khol do not describe the apparatus correctly. It

was on the 6th of August, 1809, that this first galvano-electric telegraph was made.

Dr. Samuel Thomas von Soemmering was born at Thun in 1755, and died at Frankfort-on-the-Maine in 1830. He studied at the University of Goettingen, and was professor of Anatomy at Mayence from 1785 to 1796. He then practised medicine until 1805 at Frankfort, and afterwards at Munich, where he became a member of the Academy of Sciences and a privy-councillor of the King of Bavaria.

He had, like Humboldt and others, devoted some attention to galvanism, endeavouring to solve certain physiological problems by help of the new discoveries. As early as the month of November, 1801, his attention was specially directed to the chemical action of the galvanic current, and in January, 1808, he in conjunction with the chemist Gehlen, his colleague at the Academy, communicated to that learned body the brilliant chemico-galvanic discoveries that Davy had made in the laboratory of the Royal Institution in London.

Soemmering sought, in the visible evolution of gas when water is decomposed by the galvanic current, a means of communication that should supersede the optical telegraph. In his notes occur these words:—"I did not sleep until I had realized my idea of forming a telegraph by means of the evolution of gas."

On the 22nd of July, his apparatus was so far advanced that it could work, and he wrote: "At length my telegraph is finished": "The new little telegraphic machine works well."

He continued to improve it, but it was not before the 6th of August that he thought his telegraph complete. He was delighted with it, for he made it act through a circuit of 724 feet, and his note for this day reads: "I have tried my apparatus, which is now complete, and perfectly answers my expectations. It works rapidly through wires 362 Prussian feet in length, forming a circuit of 724 feet."

Two days later this circuit was lengthened to 1,000, and on the 18th of August it was extended to 2,000 feet.

At length, on the 29th, he exhibited his apparatus before the Munich Academy of Sciences.

Baron Larrey, on his way back from the army, visited his friend Soemmering, who of course showed him the telegraph,

and it was agreed that Larrey should take it with him to Paris and exhibit it before the Institute.

The apparatus was indeed shown before the Institute, but no report upon it was made by the examining committee. No doubt Chappe's telegraph seemed to the Academy to meet all requirements.

At the time that Scœmmering was elected a member of the Academy of Sciences at Munich, there was a Russian officer named Baron Pawel Lwowitsch Schilling (of Cronstadt) attached in a military capacity to the embassy there. He witnessed Scœmmering's experiments in 1810, and was so struck by the utility of the invention, that he forthwith began to make galvanism and its applications his favourite study.

It was about this period (23rd of August, 1810) that Scœmmering invented the first electric bell, which may be thus described :—The gas rises in two tubes full of water and accumulates beneath a kind of inverted glass spoon at one end of a lever, the motion of which releases the catch of another lever. By the action of the latter a leaden ball is allowed to fall upon a bell and so the alarm is produced. This little apparatus gave much pleasure to Scœmmering. It is not figured in the description of Scœmmering's telegraph in the journal of the Munich Academy of Sciences published in 1811, which contains merely the short description we have just given.

On the 7th of September, 1810, Scœmmering and Schilling, in their telegraphic experiments, made use of wires covered with a solution of india-rubber overlaid with a varnish. This was doubtless the first time that a soluble insulating material was applied to conducting wires. Scœmmering carried the insulated wire several times round the house in which he was then living at Leyden.

In the spring of 1812, Schilling, by constant attempts to improve the insulation of the conductors, had so far succeeded that he was able to transmit the current without loss to considerable distances under water. The war about to begin between France and Russia made Schilling wishful to be able to connect the battle-field with fortified places by means of a cable of this kind. He wished also to fire mines across streams, and the method he adopted to inflame the powder was for that time rather remarkable. It consisted in igniting two

pieces of carbon cut to a point. In the autumn of 1812, he fired several mines in this way across the Neva at St. Petersburg.

Having rejoined the army at the end of 1813 he took part in the campaign in France in 1814, and on the 31st of March entered Paris with Alexander I. Here, during his stay, he resumed his experiments, and he several times exhibited in the capital the blowing up of mines by means of electric currents conveyed across the Seine.

On returning to Munich in 1815, Schilling showed Soemmering a little work published in Paris in 1805, and entitled "Manuel du Galvanism" by Joseph Izarn, professor of physics at the Lycée Bonaparte. This book mentions Romagnesi's discovery, but neither Soemmering nor his friend appears to have been struck by it as admitting of practical application. Thus they were acquainted with Romagnesi's discovery, and had read his paper published at Trent on the 3rd August, 1802, in which he announces that "Mr. Councillor Gian-Domenico Romagnesi hastens to communicate to the physicists of Europe an experiment relating to the application of the galvanic fluid to magnetism." The importance of this discovery will be understood when it is stated that it consisted of the deviation of a magnetized needle under the influence of the galvanic current.

With the year 1820, began a new epoch in the history of electricity. And from that period the future importance of the electric telegraph might be recognized.

Hans Christian Ørsted studied the effects of a voltaic current on the magnetic needle more closely than Romagnesi. Arago communicated Ørsted's experiments to the Academy of Sciences, and Delarive in September, 1820, repeated these experiments with Pictet at Geneva.

It has been stated that Ørsted was acquainted with the discovery made by Romagnesi in 1802. It had been, as we said, mentioned in Izarn's "Manuel du Galvanism," and it was likewise described in a book published at Paris in 1804 by Giovanni Aldini (Galvani's nephew), and entitled: "Essai théorique et expérimental sur le galvanisme." In this it was stated that "M. Romagnesi, the physicist of Trente, has found that galvanism causes the magnetic needle to deviate."

Ørsted, who came to Paris in 1802 and 1803, and again in 1813, was on each occasion in communication with Aldini. Izarn's manual, printed in 1805, appears to exactly reproduce the statement in Aldini's book printed in 1804. The following is the passage :

"According to the observations of Romagnesi, the physicist of Trent, an already magnetized needle subjected to the galvanic current undergoes a deviation." This is precisely what everyone has, since 1820, been accustomed to call Ørsted's discovery ; Romagnesi certainly deserves the credit of having first opened out the region which has since yielded so much to other explorers.

Aldini's book also mentions the chemist Joseph Mojon of Genoa as having observed, before the year 1804, that unmagnetized needles placed near a galvanic current acquire a kind of polarity. Izarn repeats this in his "*Manuel du Galvanism ;*" many copies of which must still exist in France, as the book was ordered to be placed in the libraries of all the high-schools.

Ampère was the first to suggest that the movements of the magnetic needle produced in this way might be useful in telegraphy ; but neither he nor any other person attempted at that period to arrange apparatus for the purpose.

It was Baron Schilling who constructed at St. Petersburg the first electro-magnetic telegraph. His connection with Soemmering had made him passionately attached to the idea of constructing a galvanic telegraph. His first apparatus consisted of a magnetic needle suspended horizontally by a filament of silk within one of Schweiger's multipliers. Under the needle was a paper disc painted in two colours so that the movements of the needle might be the better discerned. In order to give steadiness to the needle and prevent oscillations, there was attached to the needle below its centre a small piece of platinum which dipped into a vessel of mercury. For some time Schilling made use of five needles ; but by degrees he simplified his apparatus, and at length he was able to signal with a single needle and a single multiplier, producing all signals required for letters and figures by different combinations of movements in two directions.

In September of the same year, Schilling exhibited his

apparatus before a meeting of German naturalists at Bonn, in the section of physics presided over by Professor George Wilhelm Muncke of the University of Heidelberg. This gentleman was so pleased with the apparatus that he had one made like it to show to his classes ; and this apparatus is still preserved in the physical cabinet of the University of Heidelberg.

We shall now show how this telegraph, after having been imitated by Weber of Göttingen, was brought to London. It may excite some surprise to meet with the name of Lord Byron in connection with this, but there is a verse in his works which mentions the name of John William Rizzo Hoppner, who was the intimate friend of William Fothergill Cooke, the introducer of the telegraph into England.

During his stay at Heidelberg, which began in 1835, Cooke gave no thought to telegraphs or to the application of electricity to telegraphy. He was the son of Dr. William Cooke, professor of medicine at Durham, and he was staying at Heidelberg to learn how to make anatomical models in wax. At the beginning of March, 1836, his friend Hoppner, who was a student at the University of Heidelberg, told him that the professor of physics had in his cabinet an electrical apparatus by which signals could be transmitted from one room to another. This professor was no other than Schilling's friend, Georg Wilhelm Muncke, who had connected his private residence with his lecture-room by suspended wires. It was on the 26th of March, 1836, that Hoppner took his friend Cooke to one of Professor Muncke's lectures.

When Cooke had seen the apparatus and learned that it could be worked at great distances, it occurred to him that such a method of correspondence would be of great utility in England, especially in the railway tunnels which were then daily extending. He immediately resolved to abandon his anatomical studies at Heidelberg, and return to England to prosecute schemes for establishing electric telegraphs.

Cooke, who had never given much attention to general physics or even to electricity, did not become acquainted with Professor Muncke, whom he calls Moncke in his writings. He had no idea that the telegraph he saw had been invented by Schilling, and that the apparatus was made after the pattern

of instruments which the latter possessed at Bonn. Cooke gives all the credit of the invention to Gauss, whom he calls *Gaüss*.

The following was written by Cooke on this subject in 1841 :—"Having returned from India on sick leave, I was studying anatomy and making models of my dissections at Heidelberg, when, in March, 1836, I happened to witness one of those experimental applications of electricity to telegraphy which are so common, and which have been repeated for half a century without any practical result. Perceiving that the means employed in these experiments was capable of an application more useful than the illustration of scientific lectures, I immediately abandoned my anatomical studies, and devoted my whole attention to the construction of a practical telegraph."

One would hardly suppose after reading this, that Cooke had witnessed experiments performed with a copy of the electro-magnetic telegraph constructed by Schilling in Russia, and brought by him to Bonn six months before the period referred to by Cooke. The working of that apparatus is moreover mentioned by Cooke as "one of those common experiments that have been so often repeated for the last half-century," that is, anterior even to the discoveries of the galvanic battery, and of electro-magnetism !

When, in consequence of the unpleasant dissensions between Wheatstone and Cooke, Sir Isambard Brunel and Professor Daniel were, in 1840, appointed arbitrators between those gentlemen, they did not enquire into the origin of Cooke's telegraph, but in 1841 they delivered their award to the effect that "in March 1836 Mr. Cooke had for the first time witnessed at Heidelberg, where he was engaged in scientific pursuits, one of those well-known electrical experiments (so far as regards the means of telegraphic communication) which for several years have been tried repeatedly from time to time by various physicists."

Cooke also writes : "In the month of March, 1836, I was engaged in the study of anatomy at Heidelberg, when an accidental circumstance gave quite a new direction to my thoughts. Having seen an experiment in electric telegraphy performed by Professor Moncke of Heidelberg, who had, I

believe, got his ideas from Gaüss, I was so struck by the astonishing power of electricity, and so strongly impressed by the applications that might be made of it to the telegraphic transmission of news, that from that period I completely abandoned my previous occupations and devoted myself with all my energies to the practical realization of an electric telegraph—a subject on which all my efforts have ever since been concentrated. Professor Moncke's experiment was the only one on this subject that I had then seen or heard of."

Cooke tells that three weeks after he had witnessed Muncke's experiments, he had constructed, partly at Heidelberg and partly at Frankfort, a similar apparatus, but with three needles, and capable of giving twenty-six signals.

He returned to London on the 22nd of April, 1836, and he there devoted himself night and day to making a mechanical instrument set in motion by the attraction of an electro-magnet. This apparatus was in January, 1837, submitted to some of the Directors of the Liverpool and Manchester Railway, and Cooke made proposals to them for the adoption of his telegraph in the long tunnel between Edge-Hill and the Lime Street station, Liverpool. These proposals were however not accepted.

After he had twice consulted Faraday, Cooke, on the advice of Dr. Roget, called, on the 27th of February, 1837, on Professor Charles Wheatstone at his house in Conduit Street, and again a short time afterwards he called at the professor's rooms at King's College.

The result of these interviews was that in May, 1837, these gentlemen resolved to associate themselves together in an effort to introduce the use of the electric telegraph into England.

At this time Wheatstone did not know that the electro-magnet could act at great distances, and Cooke having left behind him at Heidelberg the apparatus he had made there, constructed a new one with four needles. It was generally considered that the principle upon which Muncke's apparatus was based was that which must be adopted for practical use. But neither Wheatstone nor Cooke was aware that in doing this they were adopting Schilling's plan.

A patent was granted to them, dated the 12th of June,

1837, and they determined to begin by a preliminary trial of their telegraph on a line of some length. A trial was accordingly made on the 25th July, 1837, at the terminus of the London and Birmingham Railway, on wires a mile and a quarter long, connecting Euston Square and Camden Town. This was the first time that such an experiment had been made in England with an electrical apparatus. This experiment was made thirteen days before the decease of Schilling, who died at St. Petersburg on the 7th of August, without having been made acquainted with the introduction of his telegraph into England.

On the 19th of November, 1837, Cooke and Wheatstone executed a deed of partnership, and on the 12th of December they sent a description of their apparatus to the Patent Office. In this description it was not called a new invention, but an improvement. The essential parts were in fact founded on the same principle as Schilling's invention, that is to say, on the deviation of a magnetic needle under the influence of coils. Professor Wheatstone had greatly improved the apparatus, as indeed might have been expected from so accomplished a man of science, and the needles were now kept vertical instead of being horizontal. The Abbé Moigno, in quoting a communication made to the French Academy of Sciences, says that Schilling also had used as many as five vertical needles in his apparatus. Schilling, however, never had vertical needles in his instrument.

The first apparatus made on Wheatstone's plan had five needles; these were soon reduced to two, and on some lines only one needle was used.

In justice to Cooke, we must state that it was by his efforts and his zeal that the telegraph was established in England.

After all that had been done in Europe before the month of September, 1837, by Schilling, Steinheil, Gauss and Weber, Cooke and Wheatstone, it is painful to remark that the American artist, Morse, should have been regarded by all Europe as the inventor of the electro-magnetic telegraph, although he had but made one poor experiment (4th September, 1837).

Samuel Finley Breese Morse was born in 1791, and was the eldest of three brothers. His father, the Rev. Jedediah

Morse, encouraged his son's taste for art, and Morse occasionally travelled in Europe for the purpose of copying pictures. In the course of the autumn of 1832, he was returning to America from Havre in the steamboat the *Sully*, and among his fellow-passengers was Dr. Charles F. Jackson of Boston, who had been present at Pouillet's lectures at the Sorbonne.

It will no doubt be recollected that in 1831 Pouillet had exhibited in these lectures his great electro-magnet, capable of supporting a weight of more than 2,000 lbs. During the voyage, which lasted from the 8th of October to the 15th of November, Dr. Jackson continually turned the conversation upon electricity and electro-magnetism, and suggested the possibility of telegraphy by means of electro-magnetic signals. He had on board a small electro-magnet, which he had bought in Paris at Pixii's ; and he had also a small galvanic battery.

When Morse reached New York, he resumed the practice of art, by which he earned his living, without, however, forgetting the conversations he had with his fellow-passengers on board the *Sully*.

As Morse has always been designated by the title of "Professor," it may be well to state here that he was merely professor of literature and drawing, by an honorary title conferred upon him by the University of New York.

Towards the end of 1835, Morse made trial of electro-magnetic signals, but without success. Two years afterwards, when he heard of the discoveries that had been made in Europe (his brother Sidney was the editor of a leading newspaper), he consulted with a scientific amateur, and, taking advantage of the experiments made at Princetown by Professor Henry, he constructed another apparatus, but still without any practical result.

The American Professors Henry and Bache had been in London in 1837, and had paid a visit to Wheatstone at King's College on the 11th of April, and they, as well as other Americans, knew that Wheatstone was anxious to protect his inventions in America by patents.

Morse had at that time no notion of marking paper with signs representing the letters of the alphabet. The signals he

used were limited to making figures and numerals, and from these the word intended could be found by reference to a vocabulary. Another sign (the eleventh) gave warning when numbers and not words were to be expressed. He formed each signal from two toothed types, which being successively introduced into a rule, could have a forward motion given to them. The teeth of the types raised a lever by means of which the electric current was made to pass through the line and traverse the coils of an electro-magnet that attracted an armature with an attached pencil. This pencil, while slowly passing over a roll, marked a band with zig-zags like the teeth of a saw. The signals thus indicated represented numbers which were then translated into the terms of the vocabulary.

Dr. Leonard D. Gale, professor of chemistry, who resided in the same house as Morse, had taught him how to construct the coils of electro-magnets, and had also obtained for him the necessary wires and a suitable battery. Morse made him a participator in his labours, and at a later period (1846) obtained for him an appointment in the Patent Office at Washington.

When towards the end of August, 1837, a complete account of the labours of Steinheil reached America, and was translated, for publication there, from the "*Neue Würzburger Zeitung*," a certain other American newspaper, through the influence of Morse and his brother, published on the very next day an article in which the journal that had printed the translation was soundly rated. In this article it was stated that those who inserted such statements in the European newspapers appeared not to be aware that "the electric telegraph, that wonder of our time, which is exciting the attention of the scientific public, is an American discovery. Professor Morse invented it five years ago, immediately after his return from France to America." The newspaper added: "Morse made no secret of his invention when on board of the *Sully*; on the contrary, he communicated it to all his fellow-passengers of every nationality."

Thus was it sought to make the American public believe that Schilling, Weber, Gauss, Cooke and Wheatstone had learned from Morse, the artist, the method of telegraphing by

electro-magnetism. As the newspaper also announced that Morse had his telegraph in his house, he was visited by many persons wishful to behold that "wonder of our time." Amongst these visitors was young Alfred Vail, who, with his brother George, had become very useful to Morse by their co-operation in his labours. Alfred Vail himself made at the Speedwell workshops, Morristown, New Jersey, the apparatus which was subsequently exhibited in the Capitol at Washington. This apparatus worked with more regularity than that invented by Morse. On that day, the 2nd September, Morse's machine would not work correctly. Great efforts were made to put it in order, but it was not until the 4th of September that Morse was able to make it mark numbers that represented five words, and the date. In order to express these words, 62 zig-zags and 15 straight lines were required on the paper. These signals represented the following numbers:—215, 36, 2, 58, 112, 04, 01837. By looking into the key or vocabulary, it was seen that these numbers meant:—"Successful experiment with telegraph, September 4, 1837." A fac-simile of the marks obtained on this occasion on the slip of paper is given in Silliman's "American Journal of Science and Arts," vol. xxiii., p. 168, and in the "London Mechanics' Magazine," of the 10th February, 1838.

At this time (1st of February, 1838) Morse wrote to the captain of the *Sully* as follows:—"I claim to have invented the electro-magnetic telegraph on the 19th October, 1832, on board the steamboat *Sully*, in my passage from France to the United States; consequently, I am the inventor of the first really practical telegraph founded on electrical principles. All the practical European telegraphs are founded on a different principle, and with one single exception were invented after mine."

In this strain spoke the painter Morse, after having obtained, on the 4th of September, the same result we have mentioned with the apparatus Dr. Gale helped him to make. He claims priority over all that had been done before him in telegraphy. He obtained his results a month after the death of Schilling, who, twenty-seven years previously (1810), had seen at Scemmering's in Munich, the earliest known galvanic telegraph, and who had himself, twelve years before

Morse, constructed the first electro-magnetic telegraph, which, as we have seen, was exhibited at Bonn two years later, and then transferred to Heidelberg, whence Cooke imported it into England. In the last-named country, a telegraph constructed on the same principle as that of Schilling had been working on a line a mile and a quarter long forty-one days previous to the 4th of September, 1837.

We may here observe that, at the time of his journey from London to Paris, in 1838, Morse supposed from what he heard that Schilling had not invented his telegraph until December, 1832, or 1833. This mistake induced Morse to advance that ill-founded claim to priority that we find in his letter of October, 1832. Unfortunately also, all the treatises on the electric telegraph perpetuate this error by giving 1833 as the date of Schilling's invention.

The present truly useful Morse apparatus was brought to a degree of perfection permitting of its universal adoption by the labours of Alfred Vail and his brother, and it still remains the best form of registering telegraph.

The first telegraph line worked by electricity was formed by Cooke, in 1839, between Paddington and West Drayton, on the Great Western Railway. In the following year, he laid a telegraph along the Blackwall Railway, and in 1841 did the like for the Glasgow and Edinburgh Railway. In 1843 the first-named line was extended from West Drayton to Slough. It was used on the 1st of January, 1845, to bring about the arrest of the murderer Tawell, and this circumstance had the effect of attracting attention to the telegraph, which up to that time had been little used.

In America, the first line, extending from Washington to Baltimore, was completed in 1844. On the 24th of March of that year, a phrase dictated by the daughter of Morse's friend Elsworth, the head of the Patent Office, was transmitted along the line and repeated at Baltimore. The original telegram has been preserved in the Museum of the Historical Society of Hartford (Connecticut).

To Germany belongs the credit of having been the first to establish correspondence by electric telegraph. The lines connecting the central parts of the cities of Göttingen and of Munich with the observatories of Gauss and of Steinheil

respectively, were, it is true, very short; but still they sketched out the solution of a great problem.

As early as the beginning of 1842, Wheatstone brought two of his apparatus to Berlin, where they worked in connection with a simple metallic wire supported on two poles.

The first great German line, from Mayence to Frankfort, was arranged in 1849 by Fardely, an engineer at Manheim. This trial attracted the attention of the Prussian government, and they connected the palace at Berlin with the royal residence at Potsdam by an electric wire.

Austria was not behindhand, for she had three important lines in 1851.

The first electric-telegraph communication established in Belgium was between Brussels and Antwerp. It was the result of private enterprise; but soon after its opening it became the property of the government. An Act of the Belgian parliament, dated 15th March, 1851, opened these lines to the public at a tariff of two shillings for twenty words within a circle of forty-six miles radius, and a double charge for distances beyond.

The first telegraph made in Sweden connects Stockholm with Upsala, a distance of about forty-nine miles, and it was completed in 1853. In Norway it was not before 1856 that a line was constructed to join Christiania, the capital, with Drammen.

The St. Petersburg and Moscow Railway Company, about 1852, laid a subterranean wire along their line; but, this wire soon becoming useless, the Russian government in 1854 purchased the line from the railway company, in order to make sure of the communication with Moscow, as they had already connected Cronstadt with the capital in 1853.

Switzerland appears to have been one of the first countries in Europe to appreciate the importance of the electric telegraph. A federal law dated 5th December, 1852, authorized a uniform charge of 1 franc ($9\frac{1}{2}d.$) for each despatch of 20 words, 2 francs up to 50 words, and 3 francs up to 100 words.

Matteucci laid down the first telegraph line in Italy in 1847. It is between Pisa and Leghorn. He had the apparatus made by Pierucci, the instrument-maker to the University, after patterns supplied by Bréguet.

Spain tardily followed the general movement. An experimental line, begun in 1854, on the road from Madrid to Irun, was not completed until 1856, when the public began to participate in the advantages of telegraphic communications.

It was about the year 1842 that the French telegraph authorities resolved to give the country the electric telegraph. The first electric telegraphs working in France were, one erected by Wheatstone between Paris, St. Cloud, and Versailles on the railway constructed by an English company, and another between the two first stations of the Paris and Orleans railway. Wheatstone was, nevertheless, unable to convince the French government that he could convey the electric current from Paris to Havre without any intermediate station.

Wheatstone being offended by these doubts, and vexed by being told that his French patents were of no value on account of the State monopoly, left the country with expressions of dissatisfaction.

It was not until 1844 that the French government thought seriously on the subject of the electric telegraph. By a decree of the 8th November, 1844, the minister of the interior appointed a special commission to report upon the value of the system of electric telegraphy, the advantages of that system, and the possibility of applying it. Arago, Becquerel, and Pouillet were members of this commission. On the 23rd November, 1844, the king, on the favourable report of Count Duchâtel, authorised the minister of the interior to expend 240,000 francs (£9,600) on a trial of the electric telegraph, provided the chambers would grant this amount. On the 30th of January, 1845, the stretching of wires along the railway line between Paris and Rouen was commenced. When, on the 1st of March following, the operation had been completed as far as Maisons, Bréguet and Gounelle, inspectors of the line, began a series of experiments, which were progressively extended as the length of the wires were increased. Signals were exchanged between Paris and Rouen on Sunday the 4th May, 1845, by means of an apparatus formed of a horse-shoe temporary magnet, between the branches of which was placed a magnetized needle, one pole of which was attracted by one or the other branch, according as the current was made to flow in one direction or the other.

On Sunday the 11th of June, the conventional signal given by the needle apparatus being well known to the members of the commission, the first telegraphic despatch was sent from Bréguet at Rouen to the commissioners at Paris.

The signal apparatus was afterwards tested, when another conversation took place between the stations. The time required to effect these different communications may be compared with what would be expended in writing the characters in a large hand.

Such is the history of the first trial of electric telegraphy in France. The causes which so long retarded the adoption of the electric telegraph in France will never be fully known. Injustice has certainly been done to M. Foy, who, as early as 1842, went to England for the purpose of there studying Wheatstone's electric telegraph. But when Arago himself publicly expressed in the Chamber his doubts of the possibility of transmitting the current in a single circuit from Paris to Havre, it was allowable for the director of the *aërial* telegraph to hesitate. Moreover, the interests of the *aërial* telegraph were opposed to the introduction of a system that would supersede it. The slow progress of the electric telegraph when first introduced into France was due to the influence of certain personages, and the system did not begin to develop until De Vougy became director-in-chief of the telegraph lines on the 28th October, 1853. *Aërial* telegraphy continued in use until 1855, when after having been of some service in the Crimea it was there superseded. It died hard, however, and there were some inventors, such as Dr. Jules Guyot, whose interest led them to advocate the old system in a way which at the present day we should think strange. Dr. Guyot, who was justly considered a learned man of his time, must indeed have been blinded by his own interests, when the words we are about to quote were written by him on the 30th of April, 1846 (observe the date), in a paper addressed to the Chamber of Deputies, in defence of the *aërial* telegraphs then threatened with destruction by the government proposition in which a credit for 408,650 francs (£16,346) was requested, for the purpose of replacing the *aërial* by the electric telegraph on the line to Lille.

We shall give only short quotations from this lengthy

document, first explaining the circumstance from which it arose. In 1843 a report presented to the Chamber of Deputies by Pouillet led to Dr. Guyot obtaining a grant of 30,000 francs (£1,200) for the erection of his night telegraph between Paris and Dijon. But Guyot's system, which was the result of long labours, was, like Chappe's telegraph, set aside by the introduction of the electric telegraph, and his expectation of seeing his system extended in France vanished with the recent decision of the government. The following is what Dr. Guyot said in 1846 :—

“In just the same degree as the electric telegraph is interesting as a scientific study, and as a luxury applied to the wants of large establishments, so may it likewise be termed *ridiculous* as a means of government. *Ridiculous* is the proper word, if those who cry it up are in earnest, and know no better; but *culpable* is the right term for those who do so with understanding.

“But if the electric telegraph should work perfectly, a thing which is far from having been proved, it is without any possible protection, and the executive would be at the mercy of any popular commotion, and subject to the slightest caprice of any good-for-nothing fellow who might chance to approach the line. What would happen to frail wires under such circumstances? Our country would indeed have reason to blush with shame, if she permitted the dictates of common sense to be thus opposed, and allowed the works of genius to be destroyed, for methods so feeble, and considerations so slight. The two brothers Chappe are still living; they ought to have died before, that they might not have witnessed these outrages on the great discovery to which their name is attached, and which for the last fifty years has rendered so many services to the country.

“ Be that as it may, gentlemen, the electric telegraph is not a proper government telegraph, and the day is not far distant when the truth will be fully proved. The folly of this electric telegraph business is so evident, that it must have struck even those most prepossessed in its favour. The director-in-chief (Foy) has felt it necessary to answer my objections in anticipation, in the explanation of the reasons for the change put forth by the minister, who informed me that he referred matters of telegraphy to the director.”

Farther on we read :—" Every sensible person will acknowledge that one man alone would be able to cut all the telegraph wires entering Paris, without it being possible to prevent him. We may assert that one man alone, without being stopped or even observed, could in twenty-four hours cut the electric wires of any particular line in ten places.

" It would be easy to demonstrate this assertion by a simple trial, if permission were given."

We here see how far astray a sensible man may be carried by his interests and his prepossessions. Dr. Guyot, who clearly recognised the utility of the pneumatic telegraph in the great centres of population, would have done better had he followed up that idea, as then he would no doubt have given France the "tubular post." We must not, however, be surprised at the animus shown by Dr. Guyot ; have we not heard Thiers deny the possibility of railways, and Babinet pronounce submarine telegraphs impracticable ?

To the history of this last-named means of communication we must now pass on. As we have already seen, submerged conductors were used by Schilling as early as 1812, for exploding mines. Dr. O'Shaughnessy, formerly superintendent-general of the Indian telegraphs, claims to have established, as early as 1839, a subaqueous telegraphic communication across the Hooghly. These experiments attracted little attention, and the method employed in them was not used elsewhere, nor indeed has it been described.

In 1840, Professor Wheatstone suggested to the Select Committee on Railways appointed by the House of Commons, the construction of a submarine telegraph between Dover and Calais. He afterwards developed his idea more fully in a pamphlet, which clearly showed that, as early as 1837, a correspondence on this subject was taking place between the professor and his friends.

Professor Morse relates, that in 1842 he sank an insulated wire (he does not state what was the insulating material) between Castle Green and Grosvenor Island in the port of New York, and that he proved experimentally the possibility of a submarine telegraph across the Atlantic.

In 1845, Charles West, of the firm of Silver & Co., laid an india-rubber cable across the bay of Portsmouth. This piece

of cable was made for Sir Joseph Paxton, the architect of the Crystal Palace, and Charles Dickens, the well-known novelist. West and Taylor seem about this time to have sought for authority to lay cables to Ireland and in the Mediterranean. The French government granted the required authorization, but under certain conditions which it appears West was unable to fulfil. When Brett obtained his concession in 1847, West seemed to have given up the idea of availing himself of the permission granted to him. He renewed his request, however, in 1858, for power to lay cables in France, beginning in 1862, at which period Brett's concession would expire.

In a small work he published in 1850, Charles V. Walker, superintendent of the telegraphs on the South Eastern Railway, describes the first experiment in submarine telegraphy that had been made since those of Schilling described above. Gutta-percha had just been introduced into England. Mr. Walker having obtained the authorization of the administrative commission, "on the day appointed a steam-boat was placed at my disposal, and the directors issued cards of invitation including a free passage from Folkestone to Calais or Boulogne and back.

"I had selected two miles of copper wire No. 16, covered with gutta-percha, and had myself tested it under water, piece by piece, as well as the joinings. Then I had the wire wound on a reel and brought to Folkestone.

"The sketch of the port of Folkestone (Fig. 35) will explain the details of our experiments. A branch from the main line of the railway, of about a mile in length, goes down to the port and enters the station across the moveable bridge shown in the figure. The telegraph office is the last of the lower range of buildings beyond the station. At 9 o'clock in the evening, I tested for the last time the continuity of the wire by placing the reel on the sand and connecting the covered wire with the wire proceeding from London; then with the water at our feet and by the light of the lamps, in the midst of a group of wondering fishermen, sailors and others, we found by holding a conversation with London that the circuit was good.

"It was our intention to take next day the reel into the boat, move nearly in a line with the shore, and unwinding the wire, sink it as we went along, and then remain at anchor until the

Fig. 35.—Experiments at Folkestone.]

arrival of the train from London with our guests. Then the steam-boat with our friends and the telegraphic apparatus on board would come into the position shown on the right, to take up the end of the wire. But during the night the appearance of the weather had changed : the wind rose, and the sea became so rough, that not only would the experiment have been useless, but it would have been impossible to avoid breaking the wire. It was therefore decided to join the upper wire of the over-ground line to the gutta-percha covered wire ; then, by sinking this last into the sea, to carry it round the pier and the lighthouse, and connect it with the telegraphic apparatus that was on board the steam-boat, moored alongside the pier, as shown in the figure. The conditions of experiment would thus be the same as if the steam-boat with the end of the wire had been in open sea, although the effect would be less striking.

“The operations took place on board without any previous trial, although there was great risk of the wire being broken by the waves dashing against the pier. Everything being ready, I seized the handle of the instrument and signalled the call to London (the letter L).

“I had an immediate answer to this signal. It was a quarter to one o'clock as my message passed under the waters of the Channel direct to London. These are the words : ‘Mr. Walker to the Directors. I am on board of the *Princess Clementine*. I have succeeded.’ Other communications were exchanged, and after several hours’ immersion, the wire was taken up uninjured.”

The same year Mr. Walker drew up a map of soundings in the Channel, showing the depths, and the track that would have to be followed in laying a telegraphic cable between France and England. This is nearly the direction taken by the present cable between Calais and Dover.

It was reserved for Jacob and John W. Brett to practically realise on a great scale the project that had merely been conceived by others. As early as 1845, the Messrs. Brett took out a patent for their invention of a submarine cable, having the insulating material made of india-rubber and other substances. Gutta-percha had not at that time come into use for telegraph lines. The insulating substance had to be protected

by a wrapping of twisted wire like that recently used by certain engineers.

This first patent was afterwards several times modified. Brett had proposed the use of what he termed a "vertebrated iron tubular cable" (Fig. 36), intended to protect the telegraph

FIG. 36.

FIG. 37

wire near the shores from damage by anchors and similar accidents. This cable would bear a great strain, and could be considerably bent without injury or derangement. Fig. 37 represents one of these cables strengthened by chain links for places where a still greater protection is needed.

FIG. 38.

Willoughby Smith has claimed priority for the idea of the iron protection to the cable, which was in fact adopted, and became the type of the cables laid at the present day (Fig. 38). According to him this idea was communicated to Brett in 1847, and specimens of this pattern of cable were manufactured at the workshops of the Gutta-Percha Company. The different specimens mentioned above were shown in the International Exhibition of 1851, some months before a cable was laid.

J. W. Brett has described the part taken by him in the promotion of submarine telegraphs, and we cannot do better than quote a part of his account: "It has been said that I have sought to appropriate to myself the honour of having invented submarine telegraphy. I here declare that my first idea of submarine telegraphs originated from a conversation I had with my brother in 1845, when we were discussing the electric telegraph established a short time before between London and Slough. When we were considering the possibility of an entirely subterranean line, the question arose between us: 'If this is possible underground, why not also under water? and if it answers under water, why not also on the bed of the ocean?' From that moment the possibility of a submarine telegraph took hold of my mind with the firmness of absolute conviction. But I was not aware, until 1853 or 1854, that Professor Wheatstone had previously conceived the idea of carrying a line across the Straits of Dover, and I was not even acquainted with the experiments that had

been made at the end of last century, by passing currents of frictional electricity through water.

“It is nearly twelve years since (1845) my brother and I conjointly entered, at the Government Registration Office, a plan for connecting America and Europe by the route now adopted ; in July of the same year we submitted to the Government a proposition for connecting our colonies with Great Britain, and we offered Sir Geo. Cockburn, the first lord of the Admiralty, to whom I had been referred by Sir Robert Peel, to place Dublin Castle in instantaneous communication with Downing Street, as a preliminary experiment, provided £20,000 were advanced for the expenses by the Government. As this offer was not accepted, I visited the Continent and spent much money in my efforts to advance the electric telegraph in France, Prussia, and other countries. In 1847 I succeeded in obtaining from Louis Philippe permission to connect France and England by a submarine line ; but I failed with the public, who, thinking my scheme was too risky, declined to subscribe.

“When events placed Louis Napoleon at the head of the French nation, I submitted my plan to him, and solicited his support in order to induce the public to aid the enterprise, but I was nevertheless unable to obtain more than 50,000 francs subscription.

“The first attempt at connecting France and England by means of a submarine telegraph was made in 1850, with a copper wire enclosed in gutta-percha, a substance which very opportunely came to our aid about this time. I had 27 miles of this wire taken on board of the tug *Goliath*. The wire was wound on a large iron cylinder or drum, so as to be easily paid out.

“The boat left Dover about the end of August without exciting the least curiosity. The shore end of the wire was led into a horse-box at the South Eastern railway station, and we began to pay out the wire, attaching to it pieces of lead at intervals to help in sinking it. The electrical communication between the ship and the shore was constantly maintained during the operation, and our only fear was that our slender line would break and thus cover the whole undertaking with ridicule. The attempt was however quite successful, and the

'Times' of next day remarked with justice that the jest of the evening became the reality of the morrow.

"The place selected for landing the wire on the French coast was Cape Grinez, under a cliff amidst rocks : a selection made expressly on account of the place not allowing any ships to anchor, although it is easy of access.

"My post on the railway at Dover looked over the sea, and I could see through a telescope the cliffs and lighthouse at Cape Grinez. The light of the setting sun enabled me to distinguish the dark cloud due to the smoke of the steamer moving along against the white cliffs, and thus I could follow the vessel's course. We allowed her half an hour to carry the end of the wire to the shore and to connect it with the printing apparatus. I then sent the first electric message across the Straits. The message was addressed to Louis Napoleon. I was afterwards informed that the French soldiers that saw the paper unwound with the message, from England, asked how it was possible that it could have crossed the Channel. And when it had been explained to them that electricity passing along the wire had produced the impressions of the characters, they were not less incredulous than before.

"After some further communications, the words 'All well' and 'Good night' were printed, and these concluded the experiment.

"When on the following morning we attempted to resume the communications, no answer could be got, and it soon became evident that the insulation had been destroyed, and that either the electric current was passing out at some defective point or the wire was broken. The indications of the galvanometer led us to believe that the wire had parted near the French coast, and we were able to verify this conjecture when the steamer came back. As we feared that doubts would be expressed regarding the success of our enterprise, and were also aware how important it was that the fact of telegraphic communication having been established should be proved, I sent the same night a confidential person to Cape Grinez, to obtain there the testimony of all those that had seen the messages received. A document stating the facts was attested by ten persons, including a French government engineer, who was present to watch the

operations. I sent this paper to the Emperor of the French, and one year's grace was granted me in which to make another attempt."

The success of the experiment, however, was so great and undisputable, that the promoters of the company immediately set to work, and a stronger cable, protected by a sheathing of iron wire (Fig. 38), was begun by Wilkins & Wheatherly, and finished by Newall & Co. The lengths prepared at these two

FIG. 39.

works having been found insufficient to reach the French shore, the end of the cable was fixed to a buoy, and the extra length required was made immediately by Kuper & Co., a firm which, after having been changed into "Glass, Elliott & Co.," became the great and famous concern at Morden Wharf, near Greenwich, known as the "Telegraph Construction and Maintenance Co." Three different manufacturers have therefore shared the honour of making the first permanent cable.

This cable was laid in October, 1851, between Sangate, near Calais, and the South Foreland, near Dover. The core of the

cable consisted of four copper conductors $\cdot 06$ in. diameter, each of which was coated with two separate layers of gutta-percha, which brought up the diameter to $\frac{1}{4}$ inch. The four conducting wires were twisted spirally, and the whole was wrapped in hemp steeped in tar and tallow. The cable, so formed, is pro-

FIG. 40.

tected by ten iron wires, each of $\frac{1}{4}$ in. diameter, wound spirally round it, thus bringing the external diameter up to $1\frac{1}{2}$ inch. This cable, $25\frac{1}{2}$ miles in length, weighs seven tons per nautical mile, and is laid at the maximum depth of 180 feet, which is nearly the height of the towers of Notre Dame at Paris.

This cable has several times been broken by the anchors of ships, but on each occasion there was little difficulty in quickly repairing it. In 1859, part of it was raised up by Sir Samuel

Canning, and relaid after it had been repaired and in parts renewed. Although worn by the flow of the tides, which run so strongly in the Channel, the electrical condition of the cable was found to be perfect as regards three of the wires. The fourth wire was faulty, and it deteriorated so much that in 1855 it could not be used. Fig. 40 shows a piece of this cable worn by the currents on the rocks near Dover, but the electrical condition of the section to which this piece belonged was perfect. From 1859 to the present time this cable has never lost the power of working, except in the few temporary interruptions, when the cable was quickly repaired by the engineers of the "Submarine Telegraph Co.," to whom it belongs.

CHAPTER II.

MATERIALS.

Construction of Aërial Lines — Conducting Wires — Connections — Posts — Insulators, &c.

UNTIL the last few years the conductors were formed of galvanized iron wire, of from 0·12 to 0·16 inch diameter.

From the results of ten years' experience, some engineers assert that it is more advantageous as regards durability to expend the cost of zincing the iron wires in giving them instead an increased diameter.

This expedient has moreover the advantage of increasing the conductivity of the wire and its power of resisting breaking strains.

Wire of 0·16 inch diameter is used for inland lines, and wire of 0·2 inch diameter for international lines.

The wires commonly used along the railways are of galvanized iron of 0·12 inch diameter.

The wires supplied by public contract have to be delivered ungalvanized, in weights of at least 44 lbs. without joints or solderings. The ends must be as good as the middle. Each piece must form a separate roll of 24 inches diameter, kept in shape by three ties, the total weight of which must not exceed $\frac{3}{4}$ oz. The outer extremity is marked by a loop.

The wire must be entirely of the best quality, free from flaws and all other defects. It must be covered with a coat of boiled linseed oil after having passed through the draw-hole for the last time. Every piece showing spots of rust is rejected.

A length of 33 feet of the 0·16 inch wire must weigh at least 2·2 lbs. and not more than 2·4 lbs.

The weight of the same length of 0·2 inch wire must be

from 3·5 to 3·8 lbs. The diameter must not vary beyond these limits.

The wire must be well annealed and flexible enough to be closely wound on itself in several sharp turns without breaking or splitting.

A piece of the 0·16 inch wire taken at random from any part of the roll must be able to support a weight of 10 cwt. without breaking. This strain is increased to 16 cwt. for the 0·2 inch wire.

The iron wire used in the construction of telegraph lines must have sufficient tenacity to resist the ordinary strains, and it must be flexible enough to admit of pieces being easily joined end to end.

The instantaneous testing loads are so determined as to obtain these two conditions in a proper proportion. These

FIG. 41.

loads nearly represent a strength of $2\frac{1}{2}$ tons for each square inch of section, and the strength is one which can be found only in wires of good quality after having been well annealed.

In England, the following process is adopted for winding the wire in order to make sure that it is uniform throughout its whole length. The galvanized wire, wound on a plain drum, is drawn out over three, five, or seven pulleys arranged as shown in fig. 41. Then it passes over a large grooved pulley, and finally is wound upon a drum that revolves with a velocity about 2 per cent. greater than that of the pulley. The tension to which the wire is thus exposed is a sufficient test, as any weak part is thereby detected.

Four different thicknesses of iron wire are used for the Post Office telegraphs in England, their weights per mile being respectively 200, 400, 600, and 800 lbs. Copper wire has of late been much used for telegraph and telephone lines, because

it can now be produced at much less cost than formerly with a great tensile strength and a very high conducting power. So superior in this last respect is copper to iron, that a copper wire having the same electric resistance as a given iron one is only one-sixth the weight of the latter. A copper wire will therefore cause much less strain on the posts and supports than an iron wire of the same conductivity.

Joining the wires.—The junction of the wires used to be effected by twisting them together for a distance of about

FIG. 42.

FIG. 43.

7 inches. They were also soldered together at the middle of the twisted part to prevent oxidation, and ensure the continuity of the conductor. This process had the advantage of closely joining the wires, but it also lessened their power of resisting strains. For experience showed that when ruptures occurred from a fall of temperature, they generally occurred at the places where the twist of the wire began.

For this reason, the process was abandoned and the following

substituted: About 6 or 7 inches lengths of the wires are laid alongside each other and pressed together by a vice applied in the middle. The free end of each wire is then wound tightly in a spiral form round the continuous part of the other, and the middle is soldered.

If the wires are not galvanized, their connection is completed by joining them with a thin copper wire soldered at each end of the double spiral. The copper wire is wound several times round the spirals, to prevent it from being broken, if these should come together while the wire is being stretched. To form the spiral, the ends are held in a pair of pinchers while a tool shaped like a hook is made use of. The wire round which the other is to be wound is placed within the hook, and the end of that which is to be wound on is caught in a notch formed in the curved part of the tool, which is then turned by hand. The twists obtained in this way are very close and regular, and are very quickly made (figs. 42 and 43).

The following mode of joining, which is used on several lines, is one of the best as regards conductivity and strength;

FIG. 44.

but it requires much time and care in its formation, and presents some practical difficulties as regards the soldering. The wires are placed alongside of each other after the ends have been bent into a loop; they are strongly bound together by means of a thin iron wire wound over the whole extent of the loops, and the whole is dipped into melted solder (fig. 44).

The kind of joint used in France seems to produce a good contact and to afford sufficient resistance to strain. It consists of a hollow collar of galvanized iron, provided with a groove on one of its faces. Into this the wires are introduced, their ends are flattened by the hammer, and solder is poured in through the openings.

Posts.—The posts used for supporting the conducting wires are made of fir, pine, or larch, and are saturated with sulphate of copper according to Boucherie's process. They are also

often made of iron. Larch is stronger than the two other woods, but it is not so quickly saturated. The iron posts are the most durable.

Resinous trees have until now been preferred because the posts are easily and effectively prepared of a regular shape, and the cost is moderate.

The posts are usually prepared between May and December. Trees cut between December and March having much thin sap can be injected with copper sulphate long after they have been felled; but the freezing of the preservative liquid, which usually happens from the winter's cold, makes it impossible during that season to carry out Boucherie's process. Among substances other than copper sulphate that have been hitherto used for preserving timber, we may place in the front rank creosote oil, which is obtained by distilling gas-tar. It is in general use for the preservation of the fir sleepers on railways, and in England it has been much applied to the preservation of telegraph posts.

Unfortunately, as creosote has a powerful corrosive action on organic substances, it causes the handling of the posts to be attended by much inconvenience, for it destroys the workmen's clothes and takes the skin off their hands and faces. Freshly prepared posts, moreover, have so very strong a smell as to be unsuitable for use near dwelling-houses. For these reasons the use of creosoted posts has been abandoned.

Trials were made in Prussia of chloride of zinc as a preservative, but in 1854 it was concluded that this substance could not be used advantageously, because it was liable to be dissolved out by the rain. While posts preserved by chloride of zinc keep very badly in calcareous soils, they last very long in sandy places.

Iron Posts.—Iron posts are but little used in France, England and Belgium, except in certain cases. But in India no others are used, and they are common in Australia and South America. In these countries, where wood is very quickly destroyed by the ravages of the white ant, and where the ordinary preservative processes cannot be used on account of their expense, recourse is had to iron, and thus a great number of posts can be sent by sea in a small compass.

Tubular posts of sheet iron have also been contrived. They

are made in two parts, one of which can pass within the other like the parts of a telescope. These posts, known as *Hamilton's Standards*, are also exclusively employed in British India, where

FIG. 45.

the white ant prevents the use of wood. They are composed of:—1st, two tubes, *a* and *b* (fig. 45), of sheet iron; 2nd, a cast-iron foot, *c*; 3rd, a plate or disc, *d*, also of cast-iron; 4th

FIG. 46.

welded together, and it is provided at the top with a socket for receiving the lightning conductor.

These posts vary in size according to the strain they are

a cast-iron cap, *e*; 5th, a wrought-iron lightning-conductor, *f*. In India the natives have frequently taken possession of the spikes of the lightning conductors to make into weapons by fixing them at the end of a bamboo; the spikes are therefore now riveted to the caps. The form of iron post that has found most favour in Europe, and is also met with in all parts of the world, is Siemens Brothers' tubular post, shown in fig. 46. It consists of four parts:—1st, the base, *a*; 2nd, the foot, *b*, made of cast-iron; 3rd, the upper tube, *c*, of wrought-iron; 4th, the lightning conductor, *d*, also of wrought-iron. The base is made of iron plates riveted together, and unites great firmness with an elasticity that enables it to yield to sudden or excessive strains. In the little square platform in the middle of it are four holes through which pass the screw bolts for fastening the base to the cast-iron foot. This last diminishes in diameter as it passes upwards, and terminates in a collar to receive the upper tube of the post. The latter is fixed in its place by a cement composed of sulphur and oxide of iron. It is made of a plate of iron bent round and the edges

subject to; they generally cost three times as much as wooden posts of the same strength, but they certainly last more than three times as long.

All the Egyptian lines are made with Siemens' posts, and it may be seen from fig. 47 that, notwithstanding their strength, the lines constructed with iron posts are not without elegance.

FIG. 47.—Siemens, Halske & Co.'s Posts.

In Australia, a post with a cast-iron pyramid at the base is much used. It is made by Oppenheimer of Manchester, and is represented in figs. 48 and 49. Its base has the shape of an inverted pyramid with sharp edges, and it can be forced into the ground by means of a pile-driver mounted on a tripod (fig. 49); p p' , are two simple pulleys round which pass the ropes r r' , having the handles h h' , attached to them. The

ropes carry the weight, w , by means of hooks. The cast-iron base is placed on the spot where the post is to be erected, and on the top of it a rope collar is fitted to deaden the impacts. A rod passes through the upper part of the tripod and is fixed temporarily in the base, and this serves as the guide for the weight, w , through which it passes. When w has been drawn up to the top it is allowed to fall upon the rope collar, and the operation is repeated until the top of the cast-iron base is level with the ground. The guide rod is then removed, and the iron post fixed in its place. At first the post was fixed with cement as in Siemens' system, but now it is secured by iron wedges of different sizes. These posts are very firm, and never swerve in the ground. It will easily be understood that the earth is compressed and rendered firm by the driving in of the wedge-shaped base like a stake.

A form of iron post patented by Lee & Rogers of Manchester, and known as the *riband iron post*, is made of angle irons of various heights, connected by intersecting bands of wrought-iron, which are riveted together where they cross each other and the angle irons. The whole is firmly fixed in a cast-iron foot ending in a tripod base.

This post has not been much used in telegraphy. It is elegant, but it is not very firm, and it has little resistance for lateral strains. It can rarely be used, and then only in cases where its lightness and elegance recommend it to favour.

Insulating supports.—The insulators used for supporting the conducting wires are usually formed of a porcelain bell into which an iron hook is fixed by plaster. The bell is sometimes fixed to the post by a galvanized iron stirrup and two screws, and sometimes by means of a support. One of these arrangements for a small insulator is shown in fig. 51. The larger insulator represented in fig. 52 differs from the former in size, in the shape of the stirrup, and in having a double inside bell of ebonite (hardened or vulcanized india-rubber) by which the hook is covered. A beech-wood support is interposed between the neck of the insulator and the post. This is the Belgian form of insulator. In fixing the small insulator to the post it is necessary to compress the stirrup by means of a small screw-press so that it may tightly embrace the bell. In this way the latter is

FIG. 48.

FIG. 49.

made sufficiently secure without its being prevented from turning round to allow of passing into the hook a wire already stretched.

FIG. 50.

When this form of insulator is used in curves of large radius a little wooden support is nailed to the post, and on this rests the expanded part of the bell.

This plan of fixing the large insulators has all the advantages of firmness. The proper penetration of the screw has the effect of compressing the insulator and the beech-wood support against the post, and of causing a slight indentation of the latter by the two extremities of the stirrup. From this results a suitable degree of elasticity, while the support is able to withstand a great pulling strain. This arrangement may therefore be advantageously adapted for thick wires, and for curves of small radius.

The small form of insulator is used :—1st, for wire of 0·12 inch diameter : 2nd, for wire of 0·16 inch diameter in a straight line, and on curves of large radius.

The larger form is used for supporting wires of 0·20 inch diameter, and wire of 0·16 diameter in curves of small radius.

The advantages possessed by these insulators on account of their shape are the following :—

1st. The porcelain bell, having perfectly symmetrical sections about its axis, can be turned on the potter's wheel. The thickness of the porcelain is nearly the same in every part, and this renders the firing more easy. These properties,

together with the circumstance that no part has to be fitted or cemented, combines to favour the duration of the insulator by removing the bad effect of variations of temperature. Since this form has been adopted in Belgium, the breakage of insulators occurs only in cases of malicious injury or of quite exceptional accidents.

2nd. The wire being free in the hook, and the stirrup having a certain amount of elasticity, the porcelain has only to bear

FIG. 51.

FIG. 52.

the weight of the wire : it is not, like an insulator to which the wire is rigidly attached, subjected to sudden variations of strain, and to vibrations tending to loosen it.

The internal hook is not so thick that its dilation would rupture the bell, as happens with certain forms adopted in Prussia. Now it is known that cracks in the supports are especially damaging to the insulation. It follows therefore that an insulator which on first setting up was superior to one on the Belgian system, might after some time become greatly

inferior to the latter, on account of its being liable to the causes of damage we have just indicated.

The iron stirrup does not, as has been asserted, endanger the insulation. The losses of current to the earth occur almost exclusively along the surface of the insulator on which atmospheric moisture has been deposited. The insulating property depends then on the length of that surface, and it may be increased either by increasing the height of the bell, or, as we shall presently see, by the addition of a double inside bell. The conditions arising from the use of an iron stirrup are sensibly the same as if the wire rested on the head of the insulator, and this rested on an iron bracket fixed inside, like that used in the English systems (fig. 53).

3rd. The hook being sealed into the part of the insulator that is protected by the stirrup, it is very difficult to completely break the insulator, even on purpose; when the lower part of the bell is broken, the hook continues to support the wire. In this case, the insulation is endangered in part; but the wire, not being entangled with those below it, may still be used. The interruptions that necessarily occur under such circumstances, where other insulators are used, are almost always entirely avoided.

The fixing of the hook in the insulator is effected by means of a cement made by mixing finely ground Plaster of Paris with water containing 7 per cent. of strong liquid glue. The great hardness acquired by this cement renders it possible to fix the hook without any hole having to be made for it in the porcelain. It is free also from the defect of the cement, made of sulphur and iron filings, that was formerly used, which was apt to burst the porcelain by its expansion. It is, besides, cheaper than the old cement.

A proper degree of curving is allowed to the wires when they are stretched by apparatus placed at every thousand yards on insulating supports of a particular shape.

Until lately the tension support was the only one used, either with double stretchers as in France, or with single stretchers. At the present time the *mushroom* insulator is generally used; it is traversed by a bolt carried by two stays screwed to the post. It is, on account of the iron work, somewhat higher in price, and requires more time in fitting than

the tension support mentioned above; but it has the advantage over the last of giving a better insulation and greater firmness.

FIG. 53.

FIG. 54.

FIG. 55.

On the cylindrical part of this mushroom insulator there are fitted stretchers with collars which we shall presently describe. This support serves also as a terminus to the wires on

their entrance into offices and into tunnels, and at the points of connection with subterranean or sub-aqueous lines. It also takes the place of the bell insulator in lines of irregular direction, at sharp angles. These cases occur only on high roads. The wire is then kept in this insulator by fastening to it

FIG. 56.

FIG. 57.

the two ends of a fine wire that is wound round the mushroom support.

Iron fittings of a particular form are used to support the mushroom insulator according to the different cases we have enumerated above. When it is fixed against rock or stone, flat galvanized iron supports of the form shown in fig. 56 are used; when it is attached to a flat wooden surface, then triangular supports (fig. 58) are employed.

When it is required to interrupt a wire or two at an office, the insulator called the *interruptor* is used. This is represented in fig. 57. As it is of small size, it can easily be fixed by means of square irons as in fig. 59, or by double irons (fig. 60) against a plank or any flat wooden surface.

The tenon iron, shown in fig. 61, is intended for fixing in stone walls. The hook iron (fig. 62) allows an office to be

FIG. 58.

thrown into the line wire without the necessity of fixing the support against a post or a building; for one end of the line wire is attached to the hook and the other to the interruptor carried by the iron. As this interruptor gives only a partial insulation, it can only be used in places sheltered from moisture, or on lines of short extent.

The insulators called flat, closed, and open insulators (figs. 59 and 62) which were formerly used to support the wires

wherever the placing of a bell insulator presented any difficulties are no longer employed. They were easily fitted, but

FIG. 59.

their insulation was very imperfect in damp weather. They have been replaced by the ordinary bell insulators, which are fixed on posts away from buildings, or placed beneath viaducts, or on brackets attached to the posts, or cramped into walls.

FIG. 60.

In England supports are often so attached to the posts, that a broken insulator may be replaced by simply turning a screw. Figs. 63 and 64, which explain themselves, show the method as applied to a post or to masonry.

It is usual to number the wires in the manner shown in fig. 65, so that they may be known throughout the whole route.

Stretchers, or Strainers.—Double stretchers of the form adopted in France, and single stretchers on the Belgian system,

FIG. 61.

FIG. 62.

have been generally used up to the present time. The simple stretcher is represented in fig. 66. It is formed of a cast-iron drum on the axis of which is a ratchet-wheel. The drum is divided by an opening for half its length. A support, formed of a strong slip of iron so bent as to allow sufficient space

between its extremities, carries the drum, and also a pawl which drops into the teeth of the ratchet wheel.

When this stretcher is used, the wire is brought to the bottom of the slit, and the drum is turned round by a key fitting on the axis.

This stretcher can therefore be used without the wire being cut. It thus saves the labour of joining wires, and the risk of

FIG. 63.

FIG. 64.

breakage attending such junctions. On the other hand it has a defect that restricts its use, for, not being attached to any fixed support, its mobility renders the stretching of a wire of 0·2 inch diameter a matter of difficulty. Only workmen of exceptional strength are able to thus stretch a 1,000 yards' length of wire of 0·16 inch diameter.

For this reason the simple stretcher is only used for wires of 0·12 inch diameter, and this size of wire is but rarely employed.

The double stretcher (fig. 67) is formed of two drums, each of which is supported by two plates of iron, and the parts

are connected by a key after one of them has been inserted in a hole formed in tension support. The two ends of the wire

FIG. 65.

FIG. 66.

are put through a hole in the drum. The axles of the drum carry ratchet-wheels.

The most generally used stretcher is the collar stretcher (figs. 68 and 69); the drum is carried by an iron plate attached by a key to a collar that grasps the mushroom insulator (fig. 55).

Two stretchers, of shapes that differ only so far as may be required to bring the axes of the drums into the same horizon-

FIG. 67.

FIG. 68.

FIG. 69.

tal plane, are fixed on the right and left of the support. By this stretcher a wire of 0.2 inch diameter can easily be tightened. It requires rather more time to fix them than the double stretcher, but its insulating support offers greater firmness and a better insulation than the tension support as hitherto used. This stretcher is especially advantageous in curves, because it allows the acting strain to be applied in the direction of the resistance.

It is also very convenient for stretching a wire at its termination.

All these stretchers are made of galvanized iron.

The wires wound round the drum of double stretchers must be joined by a connecting wire, soldered at each end ; and this is especially necessary in the case of collar stretchers.

Construction of Telegraph Lines.—The preliminary step to the construction of every telegraph line is the selection of the best route.

If the line has to be made where there is no network of railways, the different directions that seem to offer most advantages are compared as to cost and facility of maintenance and working.

When the route has been fixed upon, the materials are sent out. On railways the carriage is effected without expense, for stores are collected at the principal stations on the line, and are afterwards carried where required on small trucks pushed along the rails by the workmen. This operation can, however, only be carried on at certain times of the day, on account of the passing trains. It is sometimes even found, on single lines of rails, more advantageous to have the poles carried by the men over a great part of the course.

Where there are no railways, the materials are usually distributed by traction engines, or carriers are hired to convey them along the ordinary roads.

The details are thus laid down :—

The vertical distance between two wires placed on the same side of a pole is 2 feet. This interval is reduced to 20 inches, or even to 16 inches, at places where the lines cross roads or highways. The insulators attached to one side of the poles are placed in the middle of the spaces between those attached to the other side. These data give the means of calculating the height of poles required for a given number of wires. The height of the lower wire from the ground, at the middle of its span, must be at least 6 feet 6 inches along railways, 10 feet along ordinary roads, and 15 feet where a road frequented by loaded waggons is traversed.

In certain cases where the line must cross the road, the insulators are fastened to a horizontal beam, placed on poles planted on each side of the road, and sufficiently high to allow

a free passage for waggons (fig. 70). The wires should, however, not be made to cross highways unless it is absolutely necessary.

When there is a large number of wires, it is better to put up a second line on the unoccupied side of the road, instead of unduly increasing the height of the posts on one side.

This is really cheaper and safer ; for when the posts have to carry a large number of wires, they are more liable to be thrown

FIG. 70.

down, and their fall often completely stops the working of the line. When there is a double line of posts, such an accident could happen only under circumstances quite exceptional.

Posts 30 feet high are only used separately, or for short distances, or, for instance, within stations where the wires pass over many sets of rails, or where several lines branch off. They are separately used in ordinary telegraph lines wherever there is any important crossing.

Posts 24 feet high and 21 inches girth at 2 yards from the

ground are used when a strong resistance is needed. Where they have to support tension apparatus, or are placed at a sharp angle, or are exposed to strong winds, they are preferred to the ordinary posts of the same height, which have a girth of only 16 inches at 2 yards from the ground.

Posts 34 to 40 feet high, and 24 to 26 inches in circumference, are used at large crossings for holding up the wires, according as these are more or less numerous. In most cases the first-named size is sufficient. Posts even 45 to 65 feet high are used, but only in very rare cases, as for example in crossing a piece of water, or passing the wires over a building, or again, for supporting a very great number of wires when the erection of a second line would present some difficulties. In making a telegraph line we should try to give, as far as possible, a general uniform rectilinear direction to the wires, both horizontally and vertically. Changes of direction in the route and differences of height in the supports make the tension of the wires by the stretchers very low and of little use. It is therefore necessary to connect low posts with high posts by means of posts of intermediate height.

Care must be taken that the strain put upon the posts does not exceed the limits of elasticity. For a 30-foot post, sunk to a depth of 5 feet, and of 10 inches diameter at the level of the ground, the maximum strain is 1 cwt., acting at a point 1 yard from the top of the post.

This sufficiently shows the necessity of strengthening the supports at the places where wires terminate, or form sharp angles. The pulling force of a wire 0.16 inch diameter stretched in the ordinary way may amount to 2 cwt.

Where the wires go into the offices, they usually end at a bracket fixed into the masonry by irons of a particular form.

Where the wires are joined to subterranean or submarine lines, two or three posts are grouped together, according to the number of the wires, and these posts are so bound together by iron ties that they are perfectly firm. At the base of the posts there are also fixed wooden feet that serve to spread the strain over a greater extent of ground. The whole is made stable by supports placed against the foot of the post in greater or less number, according to the nature of the soil. In sharp curves the posts are kept upright by props that are fixed higher in

proportion as the strain of the wires is greater (fig. 71). When this strain reaches a certain limit, either on account of the great number of the wires, or by an increase of span, or because the angle formed by the direction of the wires is too acute, posts are connected in couples (fig. 72) by an iron bolt at the top, and again at the foot where they are placed further

FIG. 71.

FIG. 72.

apart, and props are added when required. It sometimes happens, from the shifting nature of the soil, from the necessity of avoiding the smallest displacement of the wires, and from other causes, that even these methods of obtaining firmness prove insufficient.

Recourse is then had to stays, that is to say, to ropes of twisted wires, attached at one end to the upper part of the posts, and at the other to existing fixed points, such as masses

of stonework, or stakes driven into the ground. The direction of the stays must be opposite to that of the *resultant* of the forces that act on the post. The depth to which the posts are sunk depends on the nature of the soil and the resistance to be overcome ; but in land of fair solidity, such as clay or sandy clay, this depth is generally from 5 feet for posts 20 to 30 feet high, $6\frac{1}{2}$ feet for posts 32 to 46 feet high, and 10 feet for posts

FIG. 73.

65 feet high. In soils formed of quartose, calcareous, or schistose rocks, the holes must be made by blasting or by jumping-tools. In such cases the depth is seldom more than 2 feet. The distance from post to post is commonly 100 yards in a straight line and 50 yards in curves.

Posts bearing stretching apparatus are placed every 1,000 yards. If two lines follow the same road, the most important

wires are equally divided between them ; and these wires are, as far as possible, fixed the highest on the posts, because in that position they are less liable to get out of order from the contact or rupture of other wires.

Each gang employed in the construction of the line consists of ten or twelve workmen, with occasionally the addition of one or two beginners learning the trade. A foreman or experienced line-layer has the superintendence of the workshop.

The first operation in the construction, properly so called, consists in distributing in the neighbourhood, the posts that have been sent to the different stations along the line. On

FIG. 74.

railways this is performed by means of small trucks pushed along by hand ; the distance gone through in a day of ten hours varies from four to ten miles, according to opportunities for progress, as affected by the passage of trains, according also to the dimensions of the posts, the distance of the stations, &c.

After the posts have been distributed, the next thing is fixing them. Two labourers and two young layers attach the insulating supports to the posts before these are raised up. Five or six men are engaged in making the holes in the ground, and the remainder of the gang are occupied in actually putting up the posts. Posts of moderate size are put up by hand ; those from forty to seventy feet high are raised by ropes and ladders. The holes are dug to the required depth in steps, as shown in fig. 74 at A and C. Care is taken also to make the direction of the excavation parallel to that of the wires A, and

so that the overthrowing strain on the post, shall take place against that part of the ground that has not been disturbed.

As it is desirable to disturb the soil as little as possible, various instruments have been invented for getting the earth out of the holes. For several years back, the Spaniards have used the implement represented in fig. 75, and known as the

FIG. 75.

FIG. 76.

Spanish ladle. It has *a* a metallic disc, with a cutting edge, and a rim *c* for retaining the earth, and is provided with a handle *b*. A long bar is first used to loosen the ground, then the ladle is thrust down with a turning motion, so as to penetrate into the soil, and is withdrawn filled. These operations are repeated until the requisite depth has been reached. For light lines, when the posts need not be sunk more than from

three to four feet, this method suffices ; but for heavier lines where it is necessary to sink the posts to a depth of six feet or more, the difficulty of loosening the ground at such depth prevents the use of the Spanish ladle.

Several methods of boring have lately been introduced in England, and one of the most generally used apparatus is that invented by Marshall, and represented in figs. 76 and 77. A metal disc is radially divided, so as to form a plate with

FIG. 77.

cutting edges ; when this is turned round, the earth passes through the opening between the two faces, and is raised from time to time by lifting the apparatus out of the hole. The handle terminates below the plate in an auger, which to a certain degree renders the work easier. The handle is made in several hollow pieces, the number of which varies according to the depth of the hole. A bar, and a shovel with a long handle, form part of the set of implements. The bar is used for breaking off any stones in the hole, and for beating in the soil round the post when planted.

This earth-borer appears to have answered admirably in certain kinds of ground, in spite of the covert opposition of the workmen to its employment. But it can be used only in loose ground free from stones.

In a new form of earth-borer invented by Marshall, the auger is suppressed, and a plate that forms a screw with cutting edges takes its place. The new apparatus seems cheaper than the other, and in light soils it can be worked by a single labourer.

The posts are fixed quite vertically, except in curves, where they usually have a slight outward inclination given to them.

The mean rate of progress of ten men, two layers, and a foreman, is one and a half miles a day in clayey or sandy soil.

When the posts have been fixed throughout the whole course, the placing of the wires is proceeded with. This operation is generally effected on one wire at once. A gang will on the average lay six miles of wire per day. Three workmen lay the wire along the ground; two draw it at one end, and the third unwinds it from a bobbin. These men advance continuously, and temporarily connect the ends of the wires.

Three workmen make the permanent junction of the wires, and solder them; two others, provided with ladders, place the wire on the insulators. If there are many high posts, another man will be required, either to carry a long ladder, or to go up the posts by means of climbing apparatus.

The remainder of the gang pushes along the little truck laden with the requisite tools and materials, such as iron wire to lay another line if required. When they reach the terminal post, the soldering workmen unite with those behind to stretch the wire. For this operation, six or eight men are required according to the size of the wire. One turns the drum of the stretcher, whilst the rest draw the wire by means of pinchers; the bend at this time allowed to the wire, is generally irregular and excessive. After all the wires are placed, the readjustment of the whole is proceeded with.

A gang working ten hours, generally completes the laying of two and a half miles of supplementary wire, including the fixing of insulators.

Aërial lines in English Towns.—In certain large places in England, where the construction of subterranean lines was undesirable, and where it was not possible to support the wires on posts or brackets, a system of *over-house telegraphs* has

been adopted, in which the wires are fixed to the roofs of houses. The "*Metropolitan Telegraph Company*," now, like the rest, absorbed by the Post Office, set up its lines on iron posts that supported a single wire, beneath which was suspended a light cable composed of a number of insulated wires. This system has been modified, and where such cables are maintained by the English authority they are arranged as follows :—

Only the very best materials are used in their construction. The supports are iron uprights of a height varying according to the requirements. They are attached to feet fixed on the ridges of the roofs.

All the posts used in this kind of work must be strengthened by stays in every direction. The conductor consists of a cable formed of three strands of No. 16 wire. This renders it less liable to break from its own weight, and it makes less noise than would be caused by the vibrations of a solid wire. Where it is exposed to smoke or gaseous emanations it is covered with tarred tape by which the destructive effects on the wire are much diminished. The insulators are of the form shown in the annexed drawing (figs. 78 and 79), and the result is a diminution of the friction that necessarily occurs in the long spans given to the wires. This form of insulators also reduces the risk of the wire breaking under the strain. As far as possible highways must be crossed at a right angle and not diagonally, for the shorter the crossing wires the less is the danger of breakage.

When posts cannot be fixed to the roofs, chimneys are used as points of attachment ; but in that case they must be carefully selected with regard to their stability. They are then surrounded by an iron band on which the supports are fixed. The inhabitants commonly complain of the noise caused by the vibration of the wires, and this more especially happens when the wire is too tightly stretched. In winter also the vibrations are increased by the effect of contraction. It has been attempted to obviate these inconveniences by wrapping the insulators with chamois leather, and with satisfactory results. The best way, however, of doing away with the noise is to use a piece of chain, about a yard long, on each side of the point of attachment. The wire is securely fixed and

soldered to the end of these chains, and the vibrations cease to be communicated to the chimney.

Subterranean Lines.—The wires first used in America in the original telegraphs were buried in the ground, and were made

FIG. 78.

of No. 16 copper wire, covered with cotton and steeped in thick tar. These wires, grouped together in cables of three, four, or more, were afterwards enclosed in a leaden pipe, which

FIG. 79.

was protected externally by tarred rope. At certain intervals, the ends of the wires were brought to the surface in cast-iron test boxes. The lines through tunnels were constructed in the same manner, and were placed in wooden troughs. Mr. Walker was the first to introduce gutta-percha in England, as an insulating material for the telegraph wires he laid in the

tunnels of the South Eastern Railway. Siemens, about the same time, also covered copper wires with a layer consisting chiefly of gutta-percha. About the spring of 1848 the Prussian government adopted the system of subterranean wires covered with gutta-percha. By this time Siemens had laid the foundation of a rational system of testing, and even devised a method for ascertaining the exact position of a fault, whether in the continuity of the insulating covering, or in the wire itself. At the same time he pointed out the electrical phenomena that occur in a long line, in which the subterranean wire with its insulating covering acts like a huge Leyden jar, and the induction causes a return current, as in Volta's well-known experiment.

The plan originally adopted in England for laying underground lines has been continued. Cast-iron pipes are used in places where the ground is liable to much vibration, and earthenware pipes in places not so liable. The sizes of these tubes vary according to the number of wires that require to be placed in them. Within each pipe an iron wire is left which is joined on to another, so that the cables can be pulled through the tubes.

Nearly the same method is adopted in France, and M. Ch. Bontemps gives a complete and interesting description of the laying down of subterranean lines. In the English and French system, however, the cables are introduced into tubes of narrow dimensions. So long as the tube passes in a straight line, there is no difficulty about dragging the wires through it; but it is a different matter when even a slight curve occurs; the guiding wire often breaks, and the tubes have to be opened at a great loss of time and money.

We are therefore surprised that the use of the Delperdange system has not extended. This system has been adopted in Belgium, and we shall describe it here in order to show its superiority.

The tubes for containing the cables are of cast iron, and all have a length of ten feet. Their diameters, however, range according to the number of cables they have to contain; for three, five, and seven cables, the internal diameters are two inches, two and one-third inches, two and three-quarter inches respectively.

They are one-third inch thick, and are provided throughout their whole length with a slit one inch wide, for the purpose of introducing the cable into the tube, without having to draw it through from one end. The tubes are cast with this slit at first. A bar of T-iron (fig. 80) enters the slit, and is fixed by three keys, one at each end of the tube, the other at the middle. The open space of the slit is then filled in with a cement made of iron filings, sal-ammoniac and sulphur, and this is thickly plastered on.

The joining of two tubes is thus effected: The tubes are laid end to end in a straight line, and the flanges at their extremities are surrounded by a ring of india-rubber. When water or gas pipes are joined, these rings are entire; but for telegraph lines, the ring must be cut, as it is not put in its place until after the cable has been laid. The two ends are cut so that their overlap has the same thickness as the band.

FIG. 80.

On the india-rubber rings so formed, a wrought-iron hoop is fitted in such a manner as perfectly to clip the flanges, and the turned-up ends of the hoops are fitted with a bolt and a screw, by means of which the hoop may be tightened so as strongly to compress the india-rubber. The latter is prevented from being pressed outwards at *p* by placing there a small plate of copper, between the india-rubber and the iron collar.

When the junction has been effected, the opening in the flanges, where they are traversed by the slit, must be stopped up. For this purpose a small piece of cast iron, T (fig. 82), of the exact shape of the flange and width of the slit is introduced. The T-bars are so cut at their ends as to permit the introduction of this additional piece.

At points every 216 yards apart in the subterranean line, there are tubes a yard long, provided with an enlargement in the form of a vertical cylinder, closed by a cover at the top (fig. 83). These arrangements allow an examination to be

easily made for the discovery of any faults that might occur. They are covered by the pavement, but their positions are marked on the plan of the line.

Conductors insulated by gutta-percha, and collected together in the form of a cable, are also used for passing through water-courses, tunnels and drains.

B T

FIGS. 81, 82.

FIG. 83.

In the first case, the cables are identical with those laid along the bottom of the sea to connect distant shores. The protective iron covering must always be of large size if the river is navigable, on account of the small depth of water in which the cable is laid.

In tunnels, the cables are formed singly of copper wires, insulated by a double layer of gutta-percha surrounded by hemp, and covered with marine glue. They are attached to

FIG. 84.

the sides of the tunnel by troughs, at the springing of the arch, supported by wrought-iron fixings. These fixings are placed about every yard, and such of them as connect two adjoining troughs are nearly twice as wide as the others (fig. 86).

The cables that pass through tunnels are joined to the aërial wires through boxes or posts, at which examinations can easily be made for the detection of faults.

The following is the arrangement adopted in Belgium in these testing boxes, and it answers all requirements, either on the score of insulation or on that of durability.

FIG. 85.

FIG. 86.

A cast-iron bracket (fig. 86) fixed into hewn stone by bolts, secured with lead, supports an oak board, on which is fastened a vertical plate bearing the screws. A sheet-zinc case protects the plate, and rests on the top of the bracket, where it fits tightly on the wooden base of the oak board, to which also it is fixed by screws.

The wires enter the box by two openings at the foot.

As the box is removed from the surface of the wall by the bracket, it is quite impossible for moisture to get inside the box.

When submarine cables have to be connected to the operating station, the marine line is always made to terminate in a special building, called in England the "cable house," and in this electrical tests are applied every week, to indicate the condition of the submarine line.

At Marseilles, there are two small buildings devoted to this purpose by the Eastern Telegraph Company, and situated near the entrance of the Borély park, and on the banks of the Huveaune. These two buildings, one on the right and the

other on the left bank of the river, receive several cables which pass from the sea through the Huveaune, the mouth of which is about 150 yards lower down.

Where submarine lines are connected with subterranean lines, lightning-rods (which we shall describe on another page) are placed. Some subterranean lines are laid in sewers, others in trenches. In both cases these lines are constituted of submarine deep-water cables. In the sewers they are fixed to the arch by cramps, such as we have already described. Subterranean lines are buried in the ground, to the depth of a yard, and the connections are made by joints on Willoughby Smith's system, enclosed in earthenware pipes made watertight with Portland cement. The lines of the Eastern Telegraph Company, however, have only three or four such junctions in a length of $2\frac{1}{2}$ miles. The ground in which these lines have been laid (the Prado at Marseilles) possesses very favourable conditions for the preservation of the cables, as regards moisture. In other stations of the Eastern Telegraph Company, at Aden, for instance, it has been necessary, on account of the dryness of the ground through which the line passes, to enclose it in cast-iron pipes kept constantly full of water. The duplex system of telegraphy, which has generally been adopted on this company's lines, requires a perfect insulation of the subterranean line. Now variations of temperature, or the escape from the gas-pipes of a town, causes the gutta-percha to crack in a few months, and this would occasion a loss of current such as it would be impossible to compensate in the delicate electrical equilibrium required by the duplex arrangement.

CHAPTER III.

MAKING AND LAYING SUBMARINE CABLES.

Construction of Cables—Choice of Route—Causes of Deterioration—Repairs—Taking up.

SINCE 1857, the time when the first cable between Dover and Calais was got to work regularly, marine telegraphy has made a vast progress. At least half a dozen cables cross the

FIG. 87.—Mr. (now Sir) John Pender, Chairman of the Eastern Telegraph Company.

Atlantic ocean, and even the Pacific has now been traversed, so that the telegraph encircles the globe.

English enterprise and English capital have accomplished

these splendid developments of telegraphy; and, therefore, we here place before our readers the portraits of four of the principal directors of the great telegraph companies, that have their chief offices in London (figs. 87, 88, 89 and 90).

The essential parts of a cable are: 1, the conductor for conveying the currents; 2, the insulating covering of the conductor, by which the current is prevented from passing into

FIG. 88.—Le Baron Emile d'Erlanger, of the Eastern Telegraph Company.

the sea. These two materials, when properly adapted to each other, form the core of the cable, and this, were it possible to place it at the bottom of the sea without damage, would suffice for the transmission of despatches.

This is, in fact, what was done in the experimental cable laid between Dover and Cape Grinez in 1850, and also in the cable used by the allied armies in the Crimea in 1855; but, although in the last instance it was possible to carry on the communications for eleven months, it will readily be understood that a wire covered by gutta-percha only, cannot in general be left to its fate at the bottom of the water.

The core of the cable is, therefore, generally covered by

strands of hemp or jute, either tarred or preserved in tannin; and outside of this covering, galvanized iron or steel wires are twisted, in order that the cable may be able to bear a powerful strain and receive sufficient protection. The metallic covering is preserved from rust by two inverse layers of tow mixed with silicated bitumen.

Two perfectly distinct operations must be gone through in

FIG. 89.—Sir James Anderson, of the Eastern Telegraph Company.

making a cable, and these operations are often conducted by different manufacturers. The first operation concerns the electrical conditions of the cable, and the second has for its object to enable the cable to resist the strains to which it will be exposed while being laid. According to the distances they traverse, and the depths to which they reach, cables have to fulfil certain electrical and mechanical conditions, which we shall here discuss.

Copper is always used as the conductor, because this metal offers less resistance to the passage of electricity than any other

substance. In consequence of this greater conductivity, messages can be sent better through a copper than through an iron wire of the same dimensions. The conducting quality of the wire is always carefully tested by the electricians, to see whether it answers the conditions stipulated in the contracts.

In the earlier cables, the spaces between the thin wires in the strand were not filled, and the water always reached the

FIG. 90.—Sir Daniel Gooch, Chairman of the Telegraph Construction and Maintenance Company.

copper through the pores of the gutta-percha, and then found a passage along the spaces between the wires. The wires have thus been found oxidised in nearly all the early cables. This risk has since been obviated by the use of Chatterton's composition for filling up the strand. The composition is a mixture of 3 parts by weight of gutta-percha, 1 part of resin, and 1 part of Stockholm tar, and it has the advantage of filling all the interstices in the strand, and of making the insulating layer adhere more strongly to it.

The manufacture of the copper strand is extremely simple. The bobbins on which is wound the wire for the strand, are

placed on a revolving table, which turns round the central wire. Brakes suitably check the motion of each bobbin, and allow it to be so adjusted that an equal tension may be felt in each wire. Each of the wires in the strand is unwound with a constant and uniform tension; otherwise the wire would be liable to kink and knot while it was being covered with the insulating material, through which it would force its way. Each length of wire is soldered to the next, so that no free ends shall penetrate the gutta-percha. When it is necessary to join one strand to another, the ends are made stiff by solder, and are filed to a bevel so that the two parts shall fit perfectly. A small vice, arranged for the purpose, keeps the parts together while they are being soldered. This first soldering is covered with fine wires, and again soldered so as to give the joint the strength of a solid wire.

The gutta-percha is applied warm and in a plastic state, in successive layers, while the strand is passing through a series of moulds progressively increasing in size. Between each layer of gutta-percha a coat of Chatterton's composition is interposed, and this not only increases the insulation but perfectly combines the layers of the insulating matter together (figs. 91 and 92).

As fast as it is produced the wire is laid in long troughs filled with water kept very cold. The covering quickly becomes solid and the wire is automatically wound on the drums. When it has been finished, the wire is left for some time in water to become seasoned. There are two cylinders to each machine, so arranged that there may be no stoppage; for while one is being charged with the composition the other is being emptied through the mould. It will be easily understood that in making telegraph wires it is essential to keep the wire exactly in the centre of the gutta-percha. This is done by means of guides and by the special arrangement that has already been referred to and is shown in the figure.

The joinings of the wire are done by hand, by applying to the ends, properly softened and connected together, one or two layers of plastic gutta-percha in sheets cemented together by means of the Chatterton composition (fig. 93). This operation requires great care and extreme cleanliness; but the workmen in the shops whose duty it is to make the connections soon

FIG. 91,

acquire very great skill, and it rarely happens that the joint has to be rejected by the electricians when it comes to be tested by the electrometer or by the method of accumulation. The gutta-percha keeps wonderfully under water, and would almost seem to have been purposely created for submarine telegraphy.

As to the electrical conditions that determine the dimensions to be given to the conducting wire and to the insulating

FIG. 52.

covering, it will be sufficient for us here to observe that:

1. For any given ratio between the cost of the materials (conducting and insulating) there is a corresponding proportion between the weights or the diameters of these materials by which the greatest effect is obtained at the least cost.
2. But practically the thickness of the insulator is always greater than its theoretical thickness.
3. If a constant ratio between the diameters of the conductor and the insulating material is maintained, the number of words a minute that can be sent by a given length of cable is simply proportional to

the quantity of material employed ; so the core of a cable that will transmit twenty words per minute, will weigh and cost four times as much as the core of another cable capable of transmitting only five words per minute.

India-rubber is now often used for insulating the cables. In this case it is applied to the conducting wire in spiral bands that overlap each other in opposite directions. When a

FIG. 93.—Splicing a Cable.

proper thickness has been obtained the wire thus covered is interposed between longitudinal india-rubber bands, which are united together by simple contact of the freshly-cut edges on the application of pressure. The two halves of the covering are afterwards strongly pressed and kept together by a binding of floss silk wound round the whole length of the wire. It is then wound on an iron drum turning on a pivot placed in the bottom of a plate-iron cylinder the cover of which is screwed down, and the cable is here exposed to the temperature of about 120° C. (248° Fahr.) by which it is suitably vulcanized,

for the longitudinal strips of india-rubber are previously mixed with 6 per cent. of sulphur and 10 per cent. of sulphide of lead.

The bands wound spirally round the conductor are composed of india-rubber containing the separator, that is to say, of 25 per cent. of oxide of iron, which acts by preventing the sulphur from attacking the conductor. This plan of insulation by india-rubber is the invention of Mr. Hooper, and it has given good results especially in tropical seas.

The relative value of india-rubber and of gutta-percha has great interest from a practical point of view. Gutta-percha has been much studied since 1851, as regards its electrical and plastic properties, and at the present day the air-bubbles and impurities that originally impeded its use can be completely obviated. As gutta-percha becomes semi-solid at a comparatively low temperature, its use in warm climates where it is exposed to the action of a burning sun, is, of course, attended with much risk. Gutta-percha joints are also liable to soon become damaged, unless they have been made with the greatest care by skilled workmen. On the other hand, gutta-percha possesses the most invaluable properties; it is not affected by seawater, and this is a quality that cannot be too highly appreciated; its electrical properties are such that the current received at one end of a gutta-percha cable, however long it may be, loses less than 1 per cent. of its initial power. The actually existing cables certainly approach the possible limits of perfection as regards their electrical qualities, but this does not prevent further improvements from being sought for. Mr. Willoughby Smith, the electrical engineer of the gutta-percha works of the Telegraph Construction and Maintenance Company, has succeeded in making a particular kind of gutta-percha that nearly equals india-rubber as far as regards its low specific induction. We must remember that cables, acting as so many huge Leyden jars, exhibit induction phenomena that sensibly retard the transmitted currents; india-rubber possesses in a less degree than gutta-percha this inductive capacity, and in this respect it is superior to the latter. Mr. Smith's new gutta-percha and Hooper's india-rubber have nearly the same electro-static capacity, the ratio between being 98 : 100.

India-rubber is less liable to be spoiled in working than

gutta-percha ; but since wires insulated with Hooper's india-rubber have, after they have been laid, exhibited new and somewhat unexplained phenomena, these may no doubt be referred to chemical actions arising from the mixture of various substances in the only specimen of india-rubber that has hitherto proved successful.

The electrical resistance of gutta-percha is, like that of india-rubber, much reduced by increase of the temperature. By

Shore Cable.

Deep Sea Cable.

FIG. 94.—Cable between Marseilles and Bône (Algeria).

electrical resistance we mean, the non-conducting power that renders the substance more or less insulating. The loss of current occasioned by increase of temperature, rises more rapidly in gutta-percha than in india-rubber. In this respect, therefore, the latter is superior to the former, and it also, for the reason mentioned above, allows a greater number of words per minute to be transmitted, the weights or dimensions being equal. That is to say, if two cables having like conductors be covered respectively with equal weights of gutta-percha and india-rubber, twice as many words can be transmitted through the india-rubber cable as through the other. We have already stated that with Willoughby Smith's gutta-percha, by reason of its superior insulating power and feeble induction, nearly as many words can be transmitted as with Hooper's india-rubber.

We here give (fig. 94) the section of the cable between Marseilles and Bône, in which kind of cable, Smith's gutta-percha was first employed. In this cable, which was laid in 1870, the insulation attains 1482 mégohms per knot, while the electrostatic capacity is only 0.286 microfarads. The Eastern Telegraph Company laid a second cable, in 1877, between Marseilles and Bône, and in this the dielectric was also Smith's gutta-percha. Its insulation reached 8000 mégohms per knot.

FIG. 95.

The core of the cable is always covered with hemp or jute strands in a moist state and saturated with salts or with tannin. These strands are put round the core in two spiral layers by rope-spinning machines (fig. 95), and they are applied with a certain amount of tension, so that the more the cable is stretched the greater strength they add to it. A considerable number of strands are used, and these are arranged round the core in rather elongated spirals, so as to avoid any risk of knotting or twisting it, if one of the strands should happen to break, or not be as much stretched as the others. At the same time, on

account of the plastic nature of the gutta-percha, the cordage must not press too strongly on the core. And again, the hemp covering must not only serve as a protection from the wires of the iron sheathing, but must add its own strength to that of the external covering. The hemp used at first to be covered with tar; but tannin is now preferred as a preservative, because it allows faults to be more easily detected.

Sometimes the cores of short cables connecting countries that have much inter-communication, consist of a number of wires formed into one strand; but more frequently the core is only a single wire, because it has been found more advantageous to

FIG. 96.—Cable between Cagliari and Bône.

increase the number of cables than to incur the risk of a complete interruption of all the means of communication.

The process by which cables are covered by the iron wires that form their external protection is in every respect similar to that used in the manufacture of iron ropes, and the machinery used for this last purpose can be used in making cables if a central guide be added to protect the core against unequal pressure of the iron wires. In a well-made cable, the central part should be subjected to no lateral pressure from the iron wires that are wound round it. All the machines used for this purpose leave the wire in its place without any twist, just as in wire ropes (fig. 97).

Iron cables are now covered with two reversed layers of thick tow, mixed with mineral pitch or asphalt, combined with silicate of lime to give it consistence. The machinery used in this process resembles that referred to above, and the vessel of mineral pitch is kept at a suitable temperature by steam. It is necessary not to let the cable remain too long in the trough of fused asphalt, as that would soon spoil the insulation; this

trough is withdrawn the moment the machine stops. The bitumen-covered cable is made to assume a round shape, by passing through a gauge that throws back the excess of material into the vessel where it is kept melted (fig. 98).

The wires used for making cables are generally galvanized; and this, with the protection given by the coating of Clarke's

FIG. 97.

bituminous composition, ensures the preservation of submarine lines.

A cable covered with good iron should support a ton for each pound weight of iron in a yard of its length. The numbers of wires used always range between 9 and 18, and 10 or 12 wires make a good flexible cable. Near the shore, the dimensions of the outer armour are considerably increased, in order to protect the cable against abrasions on rocks or injury from anchors. The shore cables have commonly a weight of 9 to 12 tons per knot, and some weigh as much as 20 tons. A shore cable of the largest size is shown in fig. 99, which represents the shore cable of the French Atlantic line. The strands plaited with three wires make these cables much more manageable than if they were covered by solid wires.

The Atlantic and Indian Ocean cables, which reach depths of 5,400 yards and 4,100 yards respectively, are necessarily of a more elaborate construction. In these cases, each steel wire is provided with a hemp or Manilla jute covering, which adds its own strength to that of the steel, whilst the weight of this covering adds nothing to the weight of the cable in the water. When the plaiting is carefully made, it is found that the strength of the covered wire is greater than the sum of the strengths of its parts. This is because the parts separately would give way at their weak points, and these points do not coincide in the

FIG. 98.

complete cable. Cables of this kind are the strongest and lightest that have ever been made (fig. 100).

Their breaking strain is equal to eleven times the weight in water of a nautical mile of their length; that is to say, if they had to reach a depth of eleven nautical miles, they could bear the strain without rupture. The greatest depth of the Atlantic does not exceed 2,700 fathoms, or a little more than three miles, and the modulus of rupture is therefore four times the actual strain.

Siemens also constructed the cables unsuccessfully laid by the French government between Bône and Bizerte, and between Carthagene and Ain-el-Turck, near Oran. In these cables (fig. 101), instead of the iron protecting wires there is a cover-

ing formed of strips of phosphorized copper (Muntz metal) laid spirally over the strongly woven hemp rope-work. As the copper strips overlies each other, they grasp the hemp strongly, and prevent it from contracting lengthways. A very strong and light cable is thus obtained, so that the cable we have figured is able to bear the weight of one ton before it breaks, and it would elongate to the extent of only 8 per cent. under the strain of 10 cwt.

FIG. 99.—Shore end of the Brest and Saint-Pierre Miquelon Cable.

Cables are sometimes put on board as soon as they are manufactured; sometimes, on the other hand, they are stored in tanks at the works until the steamer is ready to receive them. Fig. 102 shows the plan and section of large works with ten spinning-machines and thirty storing tanks, capable of holding as much as 2,000 nautical miles of cable. The figure also shows the plan and section of a steamboat with nine tanks. Fig. 103 represents the aft part of a steamer with the machinery for paying out the cable, and the cabin in which the experiments are conducted during the laying of a cable.

FIG 100.

FIG 101.

From the beginning to the end of the operations of constructing and laying a cable, and even after it is laid, electrical tests (of which we shall speak further on) are continuously applied.

The cable is conveyed on board by means of pulleys fixed at intervals on a rope stretching from the shore to the ship. The ships are usually supplied with flat-bottomed iron tanks, arranged along the centre and sides. The bottom plates of these are thicker than those of the sides, and the thickness of the latter diminishes from the bottom upwards. A hollow cone occupies the middle of the tank, and round this the cable is stowed in level layers. Any risk of entanglement between the layers is avoided by the use of the "crinoline." This apparatus consists (see fig. 103) of a series of concentric circles connected by ten or twelve radii, which compel the cable to arrange itself in regular layers when it is stowed in the tank. From this the cable is conducted by large cast-iron pipes to the paying-out machine. In its course the cable passes through wooden troughs in order to prevent the heat of the sun from melting the gutta-percha. In these troughs the cable passes between rollers which keep it properly stretched before it reaches the brake. And, seeing that the cable might break on board the ship, as indeed happened on the *Great Eastern* with the Atlantic cable of 1865, there were added, in 1866, six wheels between the tanks and the brake, and these wheels served as so many brakes that could press the cable between two grooved pulleys, so as to stop it and prevent it going overboard if it should part before reaching the paying-out machine.

The paying-out machinery through which the cable passes before it reaches the pulley at the stern, whence it drops into the sea, affords the means of maintaining a uniform tension on the cable, and of regulating its immersion according to the depth, so that it may not be exposed to a strain beyond that at which its elongation would endanger the core.

This amount of strain is nearly equal to the weight of a length of the cable reaching vertically from the stern pulley to the bottom of the sea, diminished by the weight of the water displaced by the cable.

The force applied to the brakes to prevent the too rapid descent of the cable must therefore be only a little less than the weight of that length of cable that would reach from the

ship to the bottom. And the paying-out machinery must be so constructed that the requisite force can be exactly applied.

It is plain that if the retarding force exactly balances the external weight of the cable, the latter will be laid quite straight; it is, however, found better to run out an excess of ten

FIG. 102.

to twelve per cent. of the cable, rather than subject it to such a strain. There is also an advantage in this should it afterwards be found necessary to pick up the cable for repairs. The effect of driving the ship at a rate as nearly as possible that at which the cable passes out is also very remarkable in reducing the strain.

We see then that the modulus of rupture of a cable should greatly exceed the maximum strain to which it will be subjected. It may, during the laying of the cable be necessary to

Fig 103.

stop the ship, and in some operations the cable has to be transferred from the stern to the fore-part of the ship. In such cases there are many additional risks of accidents. And not only has the cable to be laid sufficiently strong to ensure its duration, but that strength must after a lapse of years be great enough to allow the cable to be grappled and brought up for repairs without much risk.

The paying-out machine consists essentially of a large drum,

FIG. 104.

round which the cable takes four turns, and which is provided with two of Appold's friction brakes applied to its axle.

Above the place at which the cable comes in contact with the drum, a guide rapidly directs each turn of the cable, so that it may not overlies the preceding turn (fig. 104).

The weight of the cable paid out would be sufficient to make the drum revolve when the vessel is in motion, but sometimes it is necessary to make it revolve when the ship is stationary. The paying-out machinery is therefore provided with cylinders and pistons, and the direction of rotation can also be reversed,

so that the cable may when necessary be drawn up again over the stern, as it is in some cases a tedious and risky operation to pass the cable to the taking-up machine in the fore-part of the vessel.

Trains of wheel-work provided with a counter are connected with the axle of the machine, so that at any moment the quantity of cable paid out, and the rate at which it is passing out, can be ascertained. The ratio of the latter to the speed of the vessel is an important factor for calculating the strain. A simple arrangement indicates, by a stroke on a bell, the completion of each nautical mile paid out.

The Appold brakes, which are fixed on the axle of the drum, are smooth and rather convex wheels of about four feet diameter and nine inches width. These wheels are surrounded with steel hoops, to the inside of which blocks of hard wood are fitted at intervals. The ends of the hoops are attached at different points to the arm of a lever radial to the wheel. The apparatus is lubricated by being immersed in a tank of water. When the blocks are not sufficiently lubricated, or when the friction increases, the rim of the wheel tends to carry the blocks round with it (fig. 105). The effect of this is to turn the lever, and the result a diminution of the force of the brake. The apparatus can to a certain extent adjust itself; for the difference of distance between cb and ca on the lever being very small, it follows that by placing a weight P at the point where the greatest effect is produced, that is to say, at a , the lever will be moved by the force exercised on the circumference, in proportion to the power acting at P and the difference of the force applied at a and b . The ratio $\frac{ab}{ac}$ of the lengths of the lever represents the resultant. Assuming that the drum turns in the direction shown by the arrow, as soon as the weight P counterbalances the friction of the brake, if the co-efficient of friction between the surface increases from any cause, the strain becomes greater on a than on b , and the lever will be proportionately raised, so from the eccentric position of the points of attachment it will raise the hoop and diminish the friction. The reverse will take place if the co-efficient of friction should diminish.

The rod supporting the weight P is terminated by a piston that works in a cylinder filled with water. In this way the

shocks that might be produced by sudden variations of the strain on the cable, are avoided.

As, however, it is necessary in certain cases to relieve the cable from a part or the whole of the strain induced by the regulating brake, the end of the lever, *a*, is connected with a chain passing over a drum to which is diametrically fastened another chain that passes over a pulley, and ends at a wheel fixed on the dynamometer. In this way the effect of the

FIG. 105.

brake may be regulated at will, according to the indication of the dynamometer, without any necessity for altering the weight *P* (see fig. 104).

The dynamometer for measuring the tension to which the cable is subjected, is arranged as follows:—In front of the drum of the brake, the cable passes over a grooved pulley, fixed at about 12 yards from the stern pulley, whence the cable falls into the water. Half-way between these pulleys, the cable passes under a third pulley supporting a weight, working up and down between rollers in a vertical frame with graduated uprights. As the strain upon the cable becomes greater or

less, this pulley rises or falls in the frame, and shows by a pointer the degree of strain on the cable. The scale is made by trial.

Choice of Route.—We take the following considerations as to the choice of route from Delmarche's "Éléments de Télégraphie Sousmarine" (Paris, 1858). Apart from political, commercial, or other reasons, the choice of route should be

FIG. 106.

determined by the shortest distance, the least and most regular depths. The shortest distance requires least length of cable and a smaller vessel; the smaller the depth the less is the strain upon the cable during its laying; and the regularity of the depths obviates the dangers of suddenly varying strains.

A profile of the sea bottom along the proposed route is indispensable, and it should be as exact as possible; it is also desirable that the contour to the right and the left of the route should be known, so that the proper course may be taken if the ship should be driven out of the route laid down.

When the depths are uniform, soundings can be taken at points very far apart; but with variable depths they should be taken at least every two or three miles, until the greatest depth is reached, which generally remains the same for a considerable distance.

Another matter to carefully consider is the choice of good landing places for the cables. These should be where the

FIG. 107.

anchors of vessels are not liable to break the cable, and where there are no rocks on which the cable may be worn through by the motion of the water that always takes place near the shore. The cable should also be connected at the nearest possible distance with the earth-line at a telegraphic office or station.

The cable must be made with the requirements of the route it has to follow in view, and we have already shown why light cables do not serve for even moderate depths, where the bottom is always irregular. A heavy cable must be used whenever the depth is less than 800 yards.

The cables must be landed in barges or shallow boats that can go up to the beach. Boats of little draught can land the cable at high water, and it will be left by the receding tide. Sometimes barges must be used, but in nearly all cases the workmen have to wade through the water in actually landing the cable. This operation is represented in fig. 106, but the details, of course, vary according to circumstances.

Thick shore cables are often laid by a ship built for the pur-

FIG. 108.

pose, especially where the distance between high and low water is large, as was the case with the Atlantic cable. The steamer *Caroline* laid the shore cable in 1865 and the *William Cory* did the same for the shore cable of 1866: in both cases the cable was brought to the shore first by long boats, then by smaller boats, and finally by hand (figs. 107 and 108).

This is the method most frequently used by the *Telegraph Construction and Maintenance Company*. Other plans are also used, such as the following, adopted by the *India-rubber*,

Gutta-Percha and Telegraph Company : The first operation is to connect the ship with the shore by a rope ; to this rope a 3-inch hawser is fastened, then a 5-inch hawser, which passes over blocks firmly fixed on the shore by anchors. The cable is attached to this last hawser, which returns from the blocks on shore and is hauled in from the ship.

Shore cables weighing from ten to twenty tons per mile cannot easily be dragged along the bottom, and therefore they must be buoyed up at intervals by barrels or inflated India-rubber bags (fig. 109). These are placed every ten or fifteen yards, and support the cable by ropes passing through two upper and two lower rings (fig. 110), so arranged that when the rope is cut at *a* the cable is completely clear of the barrels and falls to the bottom. By this method, a heavy cable can be brought to shore even in the worst weather, and this is a real advantage over the old plan of landing by means of a number of boats.

FIG. 109.

When the cable between Chorillos and Mollendo on the Western coast of South America was laid, the shore end was landed by the traction of a locomotive ; for, instead of leading the hawser back to the ship, it was, after passing through the block, attached to a locomotive (L, fig. 111), moving parallel to the shore. This was the only possible method, for the bay of Mollendo is entirely filled with reefs among which boats could not pass. The same plan has been adopted at other places on the south-west coast of America,

Submarine cables are exposed to many accidents. It would at first sight seem, that a cable at the bottom of the sea would remain at rest and be subjected to no risk of damage. But this is not the case ; for irrespective of the dangers arising from faulty

FIG. 110.

construction, the enemies of submarine cables are very numerous.

The destructive agencies may be thus classed :

Physical causes :—Ice-banks ; friction against rocks ; coral-reefs ; earthquakes and submarine disturbances ; elevated temperatures on tropical shores.

Destructive animals :—Teredo, limnoria, xylophaga, sharks, saw-fishes, whales.

Accidental mechanical causes :—Anchors and fishing tackle.

PHYSICAL CAUSES.—*Ice-banks* :—The Atlantic cables nearest the North Pole are evidently more exposed than others to be

damaged or destroyed by icebergs. The depth of an iceberg below the water is at least about double its elevation above, and the stones carried by the iceberg often make the difference still greater. An iceberg rising 100 yards above the surface of the water may extend to 600 yards below it. This constitutes a great danger for the Northern Atlantic Cables. The lower parts of the icebergs, thawing as they travel southwards, come to present nothing but sharp edges and angles under the water; and these, scraping along the bottom of the sea, scoop

FIG. 111.

out deep trenches, and cut as with strong chisels any cable that may unfortunately lie in their way (fig. 112).

Rubbing against rocks.—It often happens, especially near the shore, that the bottom of the sea rises abruptly, so that the cable cannot lie uniformly along it. Hence a portion of the cable swings suspended, and the end resting on the rock has to bear the strain. A continuous backwards and forwards movement, caused by the motion of the sea, slowly but surely wears through, first the outside wires, and when these fail, the conducting wires soon break, or are worn through to the core, and thus all communication is interrupted.

When shore cables land among rocks, they should be fixed by cramps. When the beach is too rugged with rocks, cast-iron tubes, divided into two semi-cylindrical parts, are used with advantage to surround and encase the cable, so as to preserve it from any risk of damage.

Coral reefs.—In some seas these are a continual danger for cables. The coasts of Africa, the Red Sea, and the Australian

FIG. 112.

seas, for instance, are so studded with coral reefs that it is impossible to avoid them.

Earthquakes and submarine disturbances. — Interruptions from these causes are, fortunately, very rare. But the cable between Cagliari and Malta, which passes between Sicily and the island of Pantellaria, was in 1858 twice abruptly interrupted, near the isle of Maretino, by the action of submarine eruptions; and in these regions an island has been known to be thrown up and to disappear without leaving any trace.

A submarine convulsion, no doubt of a volcanic nature,

took place in 1873 on the line of the *Direct Spanish* cable that connects Spain and England, the result being a suspension of communication for several weeks. It was found, on making the repairs, that several miles of the cable were buried, and these of course were lost. In such cases it is necessary to select another route, and generally the greater the depth the less the chance of disturbance.

Elevated temperature on tropical coasts.—The temperature of a cable is usually greater near the shores and at low depths, and hence the shore cables of very warm seas should never be made with gutta-percha cores. This substance becomes plastic at 86° F. (a temperature that is sometimes found at the Antilles and in Indian seas), and the core is then liable to displacements, which may result in a loss of insulation. India-rubber stands heat better than gutta-percha at elevated temperatures, and has better insulating powers.

DESTRUCTIVE ANIMALS.—*Teredo navalis*; *Xylophaga*; *Limnoria lignorum*.—Among submarine animals, to the ravages of which cables are liable, none are more formidable than the various kinds of worms and small crustaceans that abound in every sea.

The *teredo navalis* and its congener the *xylophaga*, discovered by Professor Huxley in 1860 in one of the Levant cables, bore into the cable, and even into the gutta-percha, wherever the outside wires allow them sufficient passage.

The *teredo* is a worm that makes itself a tubular shelter by secreting calcareous matter, whilst the *xylophaga* is characterised by its bivalve form. The *xylophaga* does not penetrate far into the gutta-percha, but buries one of its valves in it. In wires of small size, the gutta-percha may thus be sufficiently entered upon to cause a considerable loss of current (fig. 113).

The *teredo* and the *xylophaga* have been met with on the Mediterranean cables, and in the Atlantic Ocean and northern seas. There are, undoubtedly, several species of it which have hitherto not been fully examined as to their destructive powers on cables.

The *teredo norvegica* (fig 113) is a worm of considerable size, provided at the head with two shell-like valves, by which it is enabled to gnaw through the hardest wood. This worm

belongs to the genus of acephalous molluscs, of which naturalists have enumerated twenty-four different species.

The *limnoria lignorum*, called also *limnoria terebrans* by Dr. Carpenter, is a small crustacean of only the size of an ant (fig.

FIG. 113.

114), and thus it can penetrate the interstices between the outer wires of the best made cables into the core, through which it bores without showing any distaste for the gutta-percha as the *teredo* does. In the Indian Ocean and the Persian Gulf, the *limnoria* attains the largest size and makes the widest holes.

It is very common about the Irish coasts, where it has seriously damaged several cables.

To mitigate the attacks of these marine creatures, the conducting wire of recently made cables has been covered by an

Fig. 114.

inner sheathing that excludes the larger animals, and this plan appears well deserving of a trial.

Sharks, Saw-fish, and Whales.—Sharks have attacked cables in Florida and left the marks of their bites. The same thing

FIG. 115.

has happened with one of the cables on the coast of China, and with one of the exposed parts of the cable between Malta and Alexandria. In the last case, one of the shark's teeth remained fixed in the gutta-percha.

In March, 1871, a fault was found in the Singapore cable, 200 miles from the shore, and Frank Buckland examined the defective part, and found in it a bone (fig. 115) which he recognised as having belonged to a sword-fish (*Pristo antiquorum*).

Sword-fishes have several times injured the cable between Para and Demerara, and such accidents have always occurred in the same localities, viz. 130 to 140 miles from Para. These creatures have, it seems, a habit of groping along the bottom of the sea, searching for food with their peculiar organ. The saw probably becomes entangled in the cable, and in the efforts made by the fishes to liberate themselves the core is injured, as shown in fig. 115. The Brazilian coast is well known to be frequented by fish of this kind, attracted by the pursuit of the whale, in which they are very active.

Whales.—This huge cetacean caused a remarkable accident to one of the Persian Gulf cables. In 1859, a whale nearly broke the first Atlantic cable as it was going over the stern of the *Magara* in the process of laying. The accident that occurred to the cable between Gwadar and Kurrachee is so extraordinary that we must quote the official report.

Mr. J. Walton, Superintendent to the Mekran and Persian Gulf telegraphs, reported to the Bombay government as follows : “The cable between Kurrachee and Gwadar, a distance of about 300 miles, was suddenly ruptured on the evening of the 4th inst. (4th July, 1872). The steamship the *Amber Witch*, Captain Bishop, with the staff of engineers and electricians under the direction of Mr. H. C. Mance, set out on the following day to repair the damage, which by experiments made at each end was calculated to be 116 miles from Kurrachee.

“The *Amber Witch* arrived at the spot at two o’clock on the afternoon of the 6th. There was a heavy sea, and a thick fog prevailed, but the cable was grappled at a quarter of a mile from the rupture.

“Soundings taken at this place were very irregular, and showed a sudden rise of 70 or 80 fathoms. In raising the cable, an unusual resistance was found, as if the cable had stuck in a rock ; but by persevering for some time, the body of an enormous whale, entangled in the cable, was brought to the surface, and it was immediately seen that it was fixed by two

and a half turns round it, just above the tail. Sharks and other fishes had partially devoured the carcass, which was so rapidly decomposing that the jaw dropped off on reaching the surface of the water. The tail, which was in good preservation, was 12 feet wide, and was covered at its extremities by many shell-fish. The whale had apparently endeavoured to make use of the cable to get rid, by rubbing against it, of these parasites, by which the cetaceans are always pestered. As the cable hung in a long bight, the animal was able not only to break it by a stroke of its tail, but to cause it to wind several times round its body."

There is plainly no safeguard against accidents of so extraordinary a nature, but this one in the Persian Gulf shows once again how important it is to avoid, by a complete examination of the submarine profile, abrupt elevations of the sea-bottom near the shores.

ACCIDENTAL MECHANICAL CAUSES.—*Anchors and Fishing-tackle.*—It is always easy to avoid anchoring grounds in the shore course of cables, and it is but rarely that the cables are lifted by ships' anchors. Captains usually know what to do in such cases, and let down again cables thus brought to the surface. The cables in the English Channel are particularly liable to damage from anchors. It frequently happens that in heavy weather ships drag their anchors in order not to be cast upon the shore. If they are in the neighbourhood of cables, of which there are many in the Channel, it will be understood that there is much risk. On the memorable night of the 2nd January, 1856, when the steamship *La Violette* was wrecked on the Goodwin Sands, and when so many other vessels were completely lost, a sailing ship, dragging her anchors, caught successively the Dover and Ostend and the Dover and Calais cables, and thus destroyed in one night the only two lines of communication then existing between England and the continent.

Fishing-tackle, especially that of coral-fishers, is a serious danger for light cables. Coral-fishing is carried on to depths of 200 yards. Below this depth the cables usually laid are what are called deep-sea cables, and are of small diameter. The coral boats are always provided with powerful capstans or winches, and their nets or drags may entangle a cable and

get wrapped round it, so that with comparatively little exertion it may be brought up to the surface. On the coasts of Algeria ruptures have often been caused by coral-fishers. There are, indeed, official instructions prohibiting coral-fishing in certain places, but the coasts are not so strictly watched as formerly, and the coral-fishers often disregard the regulations laid down by the authorities.

Repairs.—The operations required in the mending of cables are more numerous and more complicated than those required in laying them. We usually consider things dropped to the bottom of the sea at a great distance from land as utterly lost, and yet nowadays, when an interruption occurs in one of the cables in the Channel, in the Mediterranean, or even in the Atlantic, hardly a week or two passes before the cables are repaired, and the public hears of it without the least surprise. Yet the public is in general but little acquainted with the methods adopted for raising and repairing these slender cables lying at the bottom of the sea. The results are accepted as matters of course to which no importance is attached, while the submersion of the same cables has always been considered as a great feat. Nay, more, even engineers and telegraphists themselves are sometimes unacquainted with the principles upon which the repair of cables is carried on, often as the operation is required.

The first attempt to repair a cable was made on that which connects England with the Hague. Mr. F. C. Webb, the engineer of the *Electric and International Telegraph Company*, who are the owners of the cable, undertook the operation in 1853, and he has since carried it out in other cases. The rules he then laid down have since been generally adopted, but with some important modifications.

The outfit of a vessel intended for these operations includes machines both for taking up and for laying, and these two operations must sometimes be carried on simultaneously. We shall describe the raising apparatus. Two large iron or wooden beams are firmly fixed on the fore-castle, projecting above the cat-head, and between them turns a large pulley of from 2 to 3 feet diameter, and from 8 to 12 inches wide. This pulley has a deep V-shaped groove. Cast-iron cheeks bolted to the beams are fixed in each side of it, to prevent the lines or cables that

pass over the pulley slipping out when the angle between the part of the cable within the vessel and the part without is too great. This wheel is called the fore-pulley.

The *taking-up machine* represented in fig. 116 is one of a type formerly (1858) much used, but now superseded by others of a different arrangement, in which, however, the action is the same. The machine is fixed to the fore-part of the vessel, and is driven by a steam-engine of from 10 to 20 horse-power. It consists of a windlass with a large cast-iron drum of from 6 to 8 feet in diameter and from 8 to 14 inches wide, with three high projections dividing the surface into two parts, one of which, about one-fourth of the whole in width, serves to receive the hoop of a brake, whilst the other has 3, 4 or 5 turns of the

FIG. 116.

cable to be raised passed round it. The windlass is carried by an axle 7 inches in diameter, which carries a toothed wheel that engages others connected with a pulley driven by the engine. Sometimes the large toothed wheel is separate from the drum, sometimes it is bolted to it, and sometimes the teeth are cast on the inner or outer surface of the drum. The latter is the case represented in our figure, which shows the machine fitted up by Mr. Webb on board *The Monarch*. The axle of the drum often turns on supports both of which are on the inner side of the drum, so that the turns of the cable can be wound or unwound without passing the end of the cable through, or cutting it, and this is a great advantage. In some cases the drum is provided with a pawl that can be thrown in or out of gear as required.

The lines of buoys and of grapnels, chains and cables to be raised, are passed over the fore-pulley, and then make three or four turns round the drum, which is put in motion to draw in

the line or cable. In order to keep the cable tight it is made to pass into the groove of another pulley of two feet diameter placed behind the drum. The cable on leaving the drum is pressed into the deep groove by means of a "*jockey pulley*" loaded by a weight. The grooved pulley is connected with the taking-up machine, and revolves with such a velocity as to keep always the proper degree of tension on the cable wound round the drum. A wrought or cast-iron guide is fixed against the drum where the cable goes upon it. This guide makes the cable pass properly round the drum, so that one turn is not superimposed upon the other, and the cable always enters upon a clear part of the drum. This guide is adjustable, and is always case-hardened or faced with steel.

Besides this machinery there is another grooved pulley behind, similar to the one in front, and provided with brakes

FIG. 117.

for re-laying the cables. The machinery is merely the counterpart of the fore machinery, and fig. 103 will suffice to make it understood without further description.

For short distances a method of under-running the cable has been used with advantage, as it can thus be brought to the surface of the water for examination. A tackle pulley about a yard in diameter (fig. 117) in a stout iron frame is hung over the front part of the ship away from the side. It can turn on a ring, and is kept in position by chains. After the cable to be examined has been raised by grapnels, it is passed through one side of the pulley-frame, which is made to open and shut for this purpose. It is therefore unnecessary to cut the cable. The ship can then, by steaming slowly, raise up the whole cable

successively, at the same time laying it down again in its former position. This process can only be used where the depth is not great, and where the cable is not buried in sand, or entangled among rocks. But at the present day it has become almost unnecessary, as the position of the damaged point can be determined electrically with precision.

FIG. 118.

FIG. 119.

FIG. 120.

To grapple the cables, strong irons with three or four arms are used (fig. 118). Their weight may be 30 or 40 lbs. They fall to the bottom, and of course rest upon two of their arms. A chain of about 20 or 30 fathoms in length is fastened to the ring of the grapnel, and to the chain a rope of a size suitable for the work to be done. This rope is, for great depths, made of hempen strands and steel wires twisted together.

In shallow water a length of rope equal to three or four times the depth is used. Beyond 400 yards two or three times the

depth suffices. In the Atlantic, the cable was hooked with a line only one-fifth longer than the depth.

Two kinds of buoys are used. The barrel or double-cone buoys (fig. 119) serve to mark the ends of a parted cable. They are fastened to a mushroom-shaped anchor (fig. 120). This anchor is itself attached to the cable by a chain, and a

FIG. 121.

chain is also used in shallow water for attaching the buoys, but in deep seas lines are employed.

Buoys provided with a staff and a flag that may be seen at a distance mark the position of the end, and are floated near the barrel buoys. They are used also to mark any particular spot with precision.

When a cable has to be repaired, the first operation consists in finding by electrical tests the exact position of the rupture or fault. This delicate operation will be described further on. The distance and position of the fault having been found, the ship proceeds thither, the position being known by means of horizontal angles if the coast be in view, or if it be out of sight, by following a course determined by the log. In mid-ocean recourse must be had to the usual nautical observations, executed with the greatest possible accuracy. When the ship has reached the presumed locality, a flag buoy is fixed as the starting-point for further operation. The ship then throws out the grappling-iron and proceeds to drag for the cable, keeping, however, so far from the fault that if the cable be once

caught there shall be a sufficient length of cable to balance itself and prevent it from slipping over the grappling-iron without the dynamometer giving any indication of strain. If the grappling-iron catches the cable at a distance from the ruptured extremity, the part between resists by its weight, and if the cable has been laid stretched, as is always the case in deep water, the strain is very great on the raising-line and also on the cable.

If there be a tide, the drag is made with it. In this case the ship should take such a course that, making allowance for the wind and the tide, it ought to grapple the cable in the right place. A dynamometer, under which the line runs, shows the strain, and as soon as a greater strain than that due to the grapple is observed, it is known that the cable is caught. If it be concluded that the cable has been met with, the ship steams forward against the flow of the tide. As soon as the grapple line is tightened the part overboard is hauled in, until it becomes stretched and upright. The machine is then driven more slowly, so as to act only against the current due to the tide; and at this stage it is especially necessary to work cautiously, using both rudder and sails, so as to avoid letting the ship drift either to the right or left.

Too small a space would give rise to considerable strain on the grappling line, and might cause a light cable to break.

When the cable is brought on board, the strain on the line suffices to show if the broken end is near, and this determines the operations that are to follow. If the line be very slack, the suspended part of the cable may with care be brought on

FIG. 122.

board the vessel. It rarely happens, however, that the grapple hooks the cable near enough to the rupture to allow of this being done. It is nearly always impossible to tell on which side of the rupture the drag will catch the cable, and while the line is being drawn in, only its looseness will show that the fault is close at hand. If, therefore, there be no slack, the cable must be cut and tested electrically, so that the

FIG. 123.—Removing a Buoy.

shortest part may be found. The uncertainty of the position of the fault will easily be understood if we remember that the electrical error of determination must be added to that attending the nautical determination.

When the cable is large and tight, great care is required in cutting it, to prevent accidents, especially if the sea is rough. A strong chain is fastened to the cable, and is tightened and fixed on board. Another chain is also fixed on the other side of the grapple, and is allowed to run out in the sea to a certain extent, the other end being fixed on board. A man,

well secured, goes down one of the iron ladders attached to the ship's side, and he files through the cable wires, one after another, until they are weak enough to break off. The part fastened to the slack chain then falls into the sea, but is still accessible. The portion attached to the tight chain is dragged on board by means of a windlass. The electrical tests immediately indicate whether this part is in connection with the

FIG. 124.—Buoying the Cable.

shore or with the ruptured end. If the part communicates with the land, signals are telegraphed, and sometimes the result of the operations is described; and by making the proper electrical tests the exact distance of the ship from the land can be determined. The end of the cable is then carefully sealed up so as to prevent the water from penetrating within, and it is dropped into the sea with the anchor and buoy as already described.

The chain attached to the short part of the cable is then raised, with the piece of cable, the length of which may be a

quarter of a mile to five miles or more. This is hauled on board by the windlass, taking care that the ship is steered so as to avoid any horizontal strain on the cable, which might be thus damaged by being dragged along the bottom of the sea. When the rupture is reached, a buoy is anchored to indicate the position of the other end of the broken cable. This second end can therefore be grappled with the greatest ease, and the end may be brought on board without cutting the cable, even if it have been hooked so far from the rupture as to be tight. A piece of new cable is then joined to this, and the whole is sunk into the sea. If the distance be short, this can be done by the fore-pulley. If not, the cable is submerged from behind, until the first buoy is reached, marking the part in communication with the shore. This buoy is brought on board at the front part of the ship, and the end of the cable is taken aft, where the two ends are joined so as to avoid all difficulties from lines or rigging. When the splice has been made, the attaching lines are cut with a hatchet, and the cable is allowed to take its original position at the bottom of the sea.

Such is a summary of the method of repairing a cable under the most favourable conditions.

The operations just described relate chiefly to the methods used for ordinary depths. We shall proceed to consider the means employed in repairing one of the Atlantic cables brought up from depths of 3,000 and 4,500 yards. These operations, which were executed in 1866 to recover and complete the cable that was lost in 1865, are of too interesting a nature to be passed over here.

The course followed by the *Great Eastern* in her several expeditions across the Atlantic has always been determined and laid down on the chart with the greatest possible precision, and the place where the 1865 cable broke was exactly known both electrically and nautically.

The *Great Eastern* had, in 1865, passed several weeks trying to recover the lost cable. More than once it was hooked, and although the undertaking had to be given up, the time was not thrown away, since it was proved with certainty that it was possible, not only to hook the cable, but to raise it up from these immense depths. Sir James Anderson, the

captain of the *Great Eastern*, had, in fact, been able to accomplish the feat of bringing his ship across the line of the cable three times, and each time the cable was caught. The grapple line broke on each occasion, but once this occurred only when the cable had nearly been brought on board. For days and days the chief engineer of the expedition pursued his object with great and praiseworthy determination, until there was

FIG. 125.—The Great Eastern.

not a fathom of line left on board, and it became evident that the attempt must be abandoned, for that year at least.

In the year following it was renewed by using the methods and machinery we are going to describe.

The 1865 cable had been laid with about 15 per cent. of slack, and this gave hope of its being successfully raised. It had, in fact, been calculated that by hooking and raising it to the surface, the double line held suspended in the water would not be less than $9\frac{1}{4}$ nautical miles, for the depth of two miles, and that the horizontal distance, JJ, fig. 126, separating the parts of the cable resting on the ground, would be 8 miles,

thus giving an excess of 15 per cent. in the suspended part. The actual result shows that this represented pretty accurately the curve of the suspended cable.

The dimensions of the cable were: diameter, $1\frac{1}{4}$ inch; weight, 3,600 lbs. per knot in air, and 1,400 lbs. per knot in water. The total weight of $9\frac{1}{4}$ knots, suspended in water, should therefore be 12,950 lbs.; as the modulus of rupture of the cable was 15,700 lbs., it could support 11 knots of its own length in water without breaking. The idea of raising the cable at a single point was, however, abandoned, and it was resolved to raise it up by degrees. Three steam-vessels, the *Medway*, the *Great Eastern*, and the *Albany*, were consequently

FIG. 126.

fitted out with raising machinery, so that they might drag the cable at three different points, the *Medway* to the east and the *Albany* to the west of the *Great Eastern*.

The raising-up machinery for the expedition was entirely new, and had been constructed to bear a greater strain than that of the preceding year.

The grappling-iron, which was very strong, had five hooks instead of three. It was $3\frac{1}{2}$ feet high, and weighed 230 lbs. The upper ring turned on its axis, and the arms would bear a weight of 9 tons, without damage. Attached to this grapple was a chain 30 yards long, connected with a rope on board. This rope was of seven strands (fig. 127), each formed of seven smaller strands with a galvanized iron wire in its centre, surrounded with hemp. The total diameter of the rope was $1\frac{1}{2}$ inches, and it would support 30 tons. The weight in air was 10,000 lbs., and in water 7,500 lbs. per nautical mile.

Four strong beams were fixed in the fore-part of the ship, and these supported cast-iron pulleys, 4 feet 6 inches in diameter, intended for the grappling line. These pulleys projected over the cat-head so as to be clear of all obstacles, and over the centre pulley the line passed from the ship. This line was directly connected with the raising windlass, and passed beneath a dynamometer by which the strain on the line could always be read off.

The raising-up machine was the most powerful hitherto constructed, and necessarily, as it had to deal with a line capable of bearing thirty tons. This machine is represented in elevation and section in fig. 128. The five large drums, B B, each six feet in diameter, were fixed in parallel bearings ten feet apart. The grappling-line went four times round these drums, leaving on the opposite side to that on which it entered.

The winding of the line round the drums was effected by rollers

FIG. 127.

or discs, C, C, on bearings between the drums. There were four above and four below, and each part of the line was thus pushed on after having left one drum and before reaching the other. In this way, each part of the line was kept out of the way of those following. This winding required more care than with an ordinary windlass.

As the strain this machine would have to bear was very great, it was thought advisable to give motion directly to the axles B B ; these drums therefore had toothed wheels fixed on each side of them engaging the pinions E, E. By this expedient a twisting strain on the axles of the drums was avoided.

The strain on the line was thus divided between four toothed wheels with teeth four inches thick.

Each drum had a brake F, attached to its side. These brakes were acted on by an axle G G, bearing two screw motions from front to back of the machine above the brakes. The strain of these brakes was borne by the supports H H, fixed to the deck, and not by the axle G G, and this was a new application of the hoop brake.

The machine was driven by a pair of engines, which, like the machine itself, were supplied by Penn & Co. A special mechanism allowed the speed and power to be changed as required. The smallest speed, of eighty turns per minute, brought on board in one hour three-fourths of a nautical mile, and the greatest brought about double that length.

The machine was provided with a tension wheel I, and a jockey-wheel J, having an adjustable weight K, for the purpose of keeping the cable tight on the drums. A counter, or tell-tale, showed the number of turns made by the machine, and thus the length of cable raised could be known. During the raising, the cable brought on board was gradually wound up in one of the empty tanks.

The dragging for the cable was thus carried out :—The exact position of the cable having been marked by two buoys placed according to the nautical observations, the ship was brought into a position two or three miles to the north or south of the line of the buoys, according to the state of wind or current, so as to allow the vessel to drift slowly across the line of the cable.

FIG. 128.

The new cable of 1866 having being laid thirty miles to the south of the old line, there was no risk of damaging the former.

At depths of 1,900 fathoms (nearly two knots), a length of 2,200 fathoms of grappling line was paid out. This operation of paying out took an hour and a half of careful work. During

FIG. 129.

the descent of the grappling-iron and its line, the indications of the dynamometer were scrupulously observed, and the instant the grappling iron reached the bottom was immediately shown by a diminution of the strain. Then about 200 additional fathoms of line were paid out, and from that moment the dynamometer was constantly watched. The mean indications of each minute were written down, and sometimes hours were passed without these indications showing the least variation. It was interesting to observe with what regularity these mean indications remained between eight and a-half tons and nine and a-half tons. The slight variations depended only on the length of line and the power of the wind and the current.

An increase of a quarter of a ton on the strain was generally considered an indication that the cable had been hooked, and it rarely happened that this did not prove the case. No attempt at raising was made, however, until the additional strain rose to two tons. That is, as soon as a strain of ten and a-half to twelve and a-half tons was observed, the ship was put back so as to relieve the strain on the cable, and then the operation of raising was begun. At that instant the strain rose to fourteen or fifteen tons, and kept at that amount until the cable left the bottom, after which the strain gradually diminished. The attempt was once made to raise the cable without the help of other ships, and this attempt was almost crowned with success. The cable was, in fact, raised a few feet above the surface of the water, with a strain of six and a-half tons. Unfortunately the strong swell at the time made the vessel pitch, and the cable broke and fell into the sea.

After many fruitless attempts the cable was at length fished up in the following manner. It was first hooked by the *Great Eastern*, which after having taken 900 fathoms on board, suspended it from a buoy B (fig. 129). The buoy was of the largest size, weighing three and a-quarter tons, and was able to support a weight of thirteen tons. The *Great Eastern* proceeded to drag three or four miles to the east at S, and once again caught the cable. The *Medway* also hooked it at M, two miles from the *Great Eastern*, and on a signal from the *Great Eastern*, began to haul in the cable, while the great steamer did the same. The instructions given to the *Medway* were to cut the cable, if she could not raise it to the surface. This was done; the cable was cut by the *Medway* with about two hundred fathoms on board. The *Great Eastern* had thus one end of the cable forming a slack loop of about two miles length, and the tension on the grappling line was immediately much reduced. The cable was in the end fortunately brought on board, and the electric circuit with Valentia having been found good, the end that had been raised up was spliced to the cable on board the *Great Eastern*, which completed the line by laying down the 680 additional miles required to reach Heart's Content, and to connect Newfoundland with Ireland.

CHAPTER IV.

SOURCES OF ELECTRICITY.

Daniell's, Thomson's, Siemens' and Minotto's Batteries—Thomson's Trough Battery ; Callaud's, Meidinger's, Bunsen's, Grove's and Leclanché's Batteries — English Telegraph Battery — Arrangement of Batteries — Electro-magnets.

THE supply of electricity required for working telegraph apparatus may be obtained in several ways. Ohm reasoned on electricity from its analogy with heat passing along a bar heated at one end and cooled at the other, and we have thermo-electric as well as hydro-electric batteries. There are also other sources of electricity, namely, machines like the Gramme machine, that are capable of giving the same effects as a battery.

Here, however, we shall consider only those batteries that are used in practical telegraphy.

Volta was the originator of the arrangement that was named after him, the *voltaic* pile or battery. This pile dates from 1800, and was used for all the voltaic experiments made during the earlier part of the present century.

De la Rive, observing the chemical effects produced on strips of two metals (zinc and platinum) immersed in acidulated water, has given us what may be called our present form of battery. Although the experiments of De la Rive, of Jacobi, and of Moride had electro-plating for their immediate object, they gave Daniell the idea of his battery, which is merely a simple form of an electro-plating apparatus.

Daniell's first battery was very complicated (fig. 130). Possessed with the idea of giving the apparatus perfect constancy, the inventor filled it with siphons to remove the saturated saline solutions, and supply fresh water, so that a

uniform degree of saturation might be maintained in the liquids. After he had tried diaphragms of bladder, of leather, and of sail-cloth, Daniell fixed upon the porous vessels so well known to telegraphists. In Daniell's form of the cell, the zinc was inside of the porous vessel, and the copper outside. Bréguet reversed this arrangement, and definitely settled the best form of telegraph battery. This is formed of cells with two liquids, as shown in fig. 131, which represents the form that has been adopted by the French authorities. But this battery had some inconveniences, the removal of which has been attempted in certain modified forms where the porous diaphragm has been dispensed with altogether.

In all these forms of Daniell's battery, the sulphate of copper at last attacks the zinc, and thus the battery is impaired, and Daniell was perfectly justified in desiring to keep the form of battery he originally devised, because it was free from this defect. Sir W. Thomson has contrived a Daniell's battery designed to postpone this untoward result as long as possible. It is constructed as follows :—

In each cell or element of the battery the plate of copper is placed horizontally at the bottom of a glass vessel, and a saturated solution of sulphate of zinc is poured over it. The zinc is shaped like a grating, and is placed horizontally near the surface of the solution. A glass tube (fig. 132) is placed vertically in the solution, with its lower end immediately above the surface of the copper. Crystals of sulphate of copper are put down this tube, and as they dissolve in the liquid they make a solution of a greater density than that of the sulphate of zinc alone, so that the copper solution can reach the zinc only by diffusion. To retard this effect, a siphon made of glass tube filled with a cotton wick, is placed with one end about half way between the zinc and the copper, while the other end, by the action of pressure and capillarity, allows the

FIG. 130.

liquids to drop out into another vessel ; so the liquid within the cell is gradually drawn out from about the middle of its height. In this way the greater part of the sulphate of copper as it rises through the liquid by diffusion, is drawn off by the siphon before it can reach the zinc, which is thus left surrounded by a liquid that is almost entirely free from any admixture with sulphate of copper, and having a very slow downward motion counteracting the upward movement of the sulphate of copper. When the battery is in action, copper is

FIG. 131.

deposited on the lower plate, and the sulphuric acid slowly traverses the liquid until it reaches the zinc, with which it combines to form sulphate of zinc. In order that the specific gravities of the solutions should be maintained in due relation to each other, it is necessary to keep the central tube well filled with crystals of copper sulphate, and to fill up the cell with a solution of sulphate of zinc sufficiently dilute to make it the lightest stratum of liquid.

Daniell's is not the most powerful of the batteries in use. Grove's and Bunsen's have nearly double the electro-motive force ; but the chief merit of Daniell's combination is the constancy it possesses, more particularly in the practical forms that Minotto and Siemens have given to it.

The internal resistance of a Daniell's cell is generally greater than that of a Grove's or a Bunsen's cell of the same

dimensions. This defect is compensated by the length of time the cell will continue to work well, and by its emitting no noxious fumes or gases.

The Siemens-Halske battery is a modification of Daniell's, differing from the latter chiefly in the shape of the porous vessel. A (fig. 133) is the glass or glazed earthenware vessel used in all batteries. C is the diaphragm, a porous vessel which, instead of being simply cylindrical, widens out at the base where it stands on the bottom of A. It is open at both ends. K is the plate of copper, which in this case is bent into

FIG. 132.

the shape of two intersecting S's. *c* is filled with sulphate of zinc and water; *g* is a mass of *papier-maché* in pulp, heaped up above the base of the porous vessel. *z* is a ring of zinc surrounding the porous vessel and provided with a screw. The whole is filled with a saline solution, or with acidulated water, up to about half the height of the zinc. Afterward it is necessary only to keep the vessel *c* filled with crystals of sulphate of copper, and replace the water in the outside vessel from time to time. The sulphuric acid required for the formation of the sulphate of zinc is carried by the current itself through the diaphragm. The zinc need not be amalgamated,

and in order to prevent the sulphate of zinc getting mixed with the paper pulp, a thick cloth separator is placed below the paper.

These cells have too great a resistance to be used for local batteries, but they are well suited for using with long lines. No others are employed on the Indo-European line between London and Teheran.

The Minotto battery is the one used in British India, and at nearly all the stations of the submarine cable companies. It is

FIG. 133.

FIG. 134.

formed (fig. 134) of a gutta-percha vessel, at the bottom of which is placed a disc of copper having a gutta-percha covered wire attached to it to form the + electrode. Upon the plate of copper crystals of sulphate of copper are placed, and above them a separator of porous paper or cloth. Above the separator damp sawdust, B, is piled up, and upon this rests the zinc Z provided with its electrode. This form of battery is very portable, and therefore it is preferred for sending to distant stations. It remains constant without any special care. Its internal resistance is about 20 ohms, when it is in good condition. It is always used for testing submarine cable at sea, and often on land also. The advantage of having for

use at sea a battery not liable to polarization effects will be easily understood.

Another form of Minotto's battery consists of vessels made of sheet copper (fig. 135), at the bottom of which is placed about 6 lb. of sulphate of copper. This is covered with damp fir sawdust, above which rests the zinc plate pierced with a few holes. This battery is so simple that the most unpractised operator can put it together. It continues in working order for from 3 to 12 months, without being interfered with, otherwise than replacing from time to time the

FIG. 135.

FIG. 136.

water lost by evaporation. Its internal resistance is comparatively small, and it is very useful for short circuits where rather strong and continuous currents are needed.

Sir W. Thomson, in the cells he uses for working the mill and charging the bobbins of his *siphon recorder*, has yet further diminished the internal resistance of the Daniell battery and increased its power. These batteries are made of troughs about 16 inches square at the base and widened at the top; they are lined inside with lead, and contain zinc grids (figs. 136 and 137) resting on blocks of glazed earthenware. A plate of copper is soldered on the outer edge of each trough, to serve when necessary as an electrode. To facilitate the removal of the deposits of copper, a plate of that metal,

varnished on the under surface, except at the corners where it is in electrical contact with the lead, rests on the bottom of each trough. An earthenware block rests on each corner of the copper plate to support the zinc grid. The latter is wrapt in parchment paper, carefully fastened up with sealing-wax. When this paper has been moistened it acts as a porous

membrane, and retains uniformly the whole of the zinc grid which in time is worn away. A wooden framework is provided to hold the troughs, and this rests on four porcelain insulators. The whole is carefully levelled, and is so constructed that it can easily be turned round.

FIG. 137.

gravity = 1.1) is then poured into the trough, first wetting the zinc and its parchment covering. The four upper corners of the zinc and the four lower corners of the lead of the next trough having then been ascertained to be clean and dry, trough No. 2 is placed upon zinc No. 1, and the same series of operations is begun for No. 2 trough as for No. 1, and so on in succession until the battery is complete.

The crystals of sulphate of copper used in this battery must

be broken into pieces of the size of peas, and of this about 30 grammes is put into each trough and distributed equally between the earthenware blocks. A short circuit is then immediately formed for each current, and in 10 or 15 minutes the battery is ready to act with all its power.

It is necessary from time to time to add copper sulphate in equal quantities to each trough, as when the battery is first charged; but the fresh sulphate of copper should not be added until the former supply has been completely used up. From a point below the extreme level of the sulphate of zinc, enough liquid must from time to time be drawn off by the siphon to lower the level about $\frac{1}{4}$ inch, and this liquid is then replaced by adding water to the height of the zinc grid.

The internal resistance of these cells is very small, whilst their electro-motive force is considerable. It will be understood that the large consumption of copper sulphate must be kept constant, if a permanent effect is to be attained.

M. Callaud, in his treatise on batteries, thus describes the one that is known by his name:—

“The inventor’s object was to obviate the necessity of using a porous vessel in Daniell’s battery. This was accomplished by the agents used by Daniell himself; the difference of the densities of these liquids is greater than with any others used in batteries. The invention is one in which its author found more than he sought for; an electrical opposition is established between the two liquids, which keeps them separate in their super-position, and this circumstance ensures a long and good working in cells so charged. It is, in fact, a new departure in science.”

The typical form of this battery is represented in fig. 138. The outer vessel has the usual dimensions of those used in batteries for telegraph purposes. It is perforated with two holes, through which pass supports; the upper one has the

FIG. 138.

zinc attached to it, the lower one the copper. Each terminates externally in a binding screw, and an India-rubber washer is used to make the joint tight. A glass cup is supported by the zinc, and its tube reaches down to the level of the copper plate.

Water, or water containing a little sulphate of zinc, common salt, or sulphuric acid, is poured into the vessel, while the cup is filled with a solution of copper sulphate. This very heavy solution falls to the bottom of the vessel, and, without mixing with the other liquid, raises up the latter until it reaches the zinc.

“The electric current is produced immediately. Crystals of copper sulphate are thrown into the cup, and there keep the solution saturated, in spite of the working of the battery.”

“This battery is easily used, and has the advantage of being covered up. In it the inconveniences caused by porous vessels, which have already been mentioned in speaking of the Daniell cells, are completely avoided. The French government and railway telegraphs make use of great numbers of cells enclosed in boxes ; the Callaud cells arranged for this purpose are very simple. They are shown in fig. 140.

“These cells are charged in the same way ; but as they have no glass cup, a siphon or funnel is used in adding the solution of copper sulphate. Another arrangement is to hang the zinc to the edge of a plain vessel. The Callaud cells lessen the costs of maintaining telegraph batteries by 60 per cent. ; a circumstance proved by the reports that telegraph inspectors have given to their directors in cases where this plan is adopted. We have here, depend upon it, a solution of the problem of cheap electricity ; at least, this is one of the most economical sources of electricity.

“The experience of twenty-five years has confirmed its advantages. It is used by telegraph companies in France, Spain, Italy, Germany and England. In the United States of America great numbers of these cells are used.”

Cells with two liquids of different densities have been contrived in other countries as well as in France ; and we have already seen that Sir W. Thomson's cell much resembles that of Callaud. Meidinger's cell (fig. 140) is used in Germany, and its shape is like a battery that has long been used in France.

The form of Callaud cell used in America differs materially from the French type. The vessels are 9 inches high and 7 inches in diameter. The zinc is cast into the shape of a four-armed wheel without teeth, and is supported by a rod in the centre (fig. 141).

We have now to examine the other hydro-electric batteries for telegraphic purposes that differ from those of the Daniell type. Of Grove's battery, used more particularly in England and in Germany, it will be sufficient to state that the form

FIG. 139.

FIG. 140

known in telegraphy is that invented by Poggendorff. The porous vessel is cylindrical, the platinum that forms the conducting electrode is bent into the s shape, in order to afford a larger surface. This platinum passes through a porcelain stopper that closes the porous vessel. But in Germany Bunsen's battery is preferred to Grove's.

The idea of substituting retort coke or carbon for platinum appears to be due to Grove, who made some trials of carbon in London. He abandoned this plan, which was again taken up by Bunsen in 1843. The typical form of this battery is shown in fig. 142. *v* is the external vessel of brown glazed stoneware. The zinc *z* is made of a sheet $\frac{1}{5}$ inch thick,

bent into a cylindrical shape. It is carefully amalgamated, to prevent its rapid solution. A plate of red copper, rivetted to the zinc, forms the negative electrode of the arrangement. This plan is preferred to the use of a screw pressing strongly on the zinc. P is the porous vessel, in which a square prismatic block of retort coke is placed. The top of this piece of coke is covered with a layer of electrolytically deposited copper, to which a strip of red copper is fixed. The porous vessel is filled with nitric acid diluted with water, and into the stoneware jar containing the

FIG. 141.

FIG. 142.

zinc, water acidulated with 10 or 12 per cent. of sulphuric acid is poured.

In the Leclanché battery the outer vessel is square, with a neck into which the porous vessel fits rather closely, so as to considerably diminish the evaporation (fig. 143). This neck has a longitudinal enlargement to allow a rod of zinc to pass through it, and liquids to be poured down. The zinc is of drawn metal, with an electrode of galvanized iron wire fixed into its upper end. The porous vessel is filled with powdered retort carbon and peroxide of manganese in equal quantities. In the middle of it is a plate of coke, on which a leaden head is cast to form the negative electrode of the cell. The outer vessel is only half filled with water, and then chloride of ammonium is added.

Leclanché has lately modified the form of his battery. He now compresses the mixture of peroxide of manganese and coke by means of a hydraulic press ; and with a little shellac he is able to consolidate the whole together with the conducting plate of carbon into a cylindrical form. In this way the porous vessel is dispensed with. The zinc, of the same shape as before, is separated from the carbon cylinder by pieces of wood, and is kept in its place by India-rubber rings (fig. 144).

FIG. 143.

FIG. 144.

This battery is the cleanest and most convenient with which we are acquainted. It can remain a very long time without attention, if it be used for the purposes for which it is intended. The great railway companies in France employ scarcely any other battery, and there are stations where it is still working perfectly after having been nine years in use.

A simple and convenient form of Daniell's battery which is very commonly used in England for telegraphic purposes may here be described. It consists of a long trough or box, for it is generally provided with a lid, and a quite usual size for it is 2 feet in length, 6 inches wide, and $5\frac{1}{2}$ inches deep. This is divided by transverse partitions of

slate into a number of separate cells, of which in a 2 feet trough there are usually ten. The whole of the interior, including the slate partitions, is coated with a composition of India-rubber and shellac, so that there may be no leakage or any liquid communication between the cells. Each cell is then subdivided by a plate of porous porcelain into two parts. A slip of copper hanging over the top of each slate partition connects a sheet of copper 3 or 4 inches square, with a thicker piece or slab of zinc ; the last copper at one end of the trough is connected with the binding-screw, and the last zinc at the other end with a similar binding-screw. The subdivision of each cell which contains the copper plate is filled with solution of sulphate of copper, and crystals of that substance also occupy the lower part of the division. The zinc cells are filled with very dilute acid, or with a saline solution, and the electro-chemical action takes place only when the poles are connected through the line wire, in the manner presently to be pointed out. The advantages claimed for this form of apparatus are simplicity of construction and immunity from the risk of accidental injury in use or in transport.

We shall not dwell further on this subject. The batteries we have just described are those particularly used in telegraphy.

We have purposely omitted the Marié-Davy, which has gone completely out of use, because the mercurial salts by which it works are dangerous to handle. Thermo-electric piles are little used in telegraphy.

We have just seen that a voltaic battery may be made in many different ways, but in all cases a combination of three things is required, of which one at least must be a liquid ; the others are generally metals. When the combination is well chosen, the force to which it gives rise, or what is usually called the electro-motive, remains latent or manifests itself, according as the connection of the three parts of the combination is interrupted or complete. This will more easily be understood if we suppose the three elements of the combination to form a triangle, the base of which represents the acidulated water, and the sides the two metals. So long as the triangle is entire without a break, the electro-motive force shows itself in circulation, in a determined direction

continuously through the sides of the triangle. But the moment any one of the sides of the triangle is removed, whether it be the zinc, the copper, or the liquid, the force ceases to act. The action can, however, be restored by means of a wire, though it may be a very long one, connecting the two poles of the combination, or even if each pole be connected through wires with the earth. These results can easily be demonstrated by very ordinary appliances ; but when the size of the apparatus is increased, and arrangements are made for magnifying the effects, the phenomena are very marked, and can be made to give rise to very decided mechanical effects.

A wire placed in the positions just mentioned acquires those magnetic properties upon which the telegraph is based. If the wire be wound round a soft iron core, the latter is magnetized while the current passes through the wire, and the magnet so formed will attract other pieces of iron, so that movement can thus be imparted to a piece of machinery. Or again, if this wire is placed round or near a magnetized needle, the latter can be at will deflected to the right or left by the current, and thus produce the visual signals of a preconcerted code.

Let us now see how the wire must be used, and how the power it possesses can be multiplied or re-inforced, so that it becomes capable of practically producing the effects required for electric telegraphs. The properties acquired by the wire affect its whole length, but their intensity is modified by that length. The wire must always be considered as offering a resistance to the passage of electricity, and the longer it is, and the thinner it is, the greater is that resistance. This resistance, however, does not affect the practical rapidity with which the force is transmitted, and it is most important to understand that it diminishes the effect only by reducing the quantity of electricity that is put in motion. Again, the amount of the force is the same at every part of the circuit ; so that, if the wire is made thicker at any part of the circuit, the general resistance is diminished, and in a given time a greater amount of electricity passes through each part of the circuit.

If a wire joining the two metals be bent into this form , the current passes up one side and down the other, but if the sides be connected by a cross-piece, made of wire of the same thick-

ness, thus, **A**, then a portion only of the current will pass the upper point, and the rest will take the shorter path, and the total amount passing will also be greater than before. If the cross-piece forms an equilateral triangle with the other parts,

FIG. 145,

then that cross-piece will convey two-thirds of the total current, and only one-third will pass through the vertex. This is the principle of derived currents or "shunts."

A single voltaic cell being usually incapable of producing the required effects, it is necessary to connect several cells in order to obtain the desired results, and the effects will vary according

to the manner in which the cells are combined. The batteries, like conducting wires, have their own resistances, which may be increased and diminished by various arrangements. Let us suppose, for instance, that we have six pairs of metals, and let fig. 145 represent various combinations of these, the thick lines being the zinc and the thin lines the copper.

In A (fig. 145) the elements are arranged "for tension," and if E stand for the amount of the electro-motive force of each element, and R for the resistance, it is clear that the battery of six cells will have an electro-motive force of $6 E$, and a resistance of $6 R$. But the cells may be combined "for quantity," as shown at B. The electro-motive force of this arrangement will still be E , but its resistance will only be $\frac{R}{6}$.

The cells may also be joined in two's for tension, and in three's for quantity as at C; in this case the electro-motive force will be $2 E$ and the resistance $\frac{2}{3} R$. Again, the cells may be connected as at D, in three's for tension and in two's for quantity; the electro-motive force will be $3 E$ and the resistance $\frac{3 R}{2}$.

It will be observed, therefore, that with a sufficient number of cells, a battery can be arranged which shall have as great an electro-motive force and as small a resistance as may be desired. Practically, in electric telegraphy we require only to increase the electro-motive force without paying any attention to the resistance. This, however, is easily provided for by increasing the size of the battery cells.

We have stated that the current of a battery passing through a wire deflects a magnetic needle. If the needle be suspended vertically on its centre with its north pole upwards, and a wire in front of it be also vertical with a descending current, the upper part of the needle will be deflected to the right. If the current be made to rise behind the needle after it has passed down in front, the action will be concurrent with the former, and in fact the power of the current in the needle will thus have been doubled; and by repeatedly passing the wire before and behind the needle the apparatus can be made sensitive to very feeble currents. This invention of the multiplier or galvanometer is due to Schweigger. By using two parallel

needles with their poles reversed in position, the apparatus becomes still more delicate; but the most sensitive apparatus of the kind is Sir William Thomson's mirror galvanometer, which will be described in the next chapter.

Advantage has been taken of the action of currents on the magnetic needle in the formation of telegraphic apparatus in which the signals are produced by the deflection of the needle to the right or left, according to the direction given to the current.

As the action of currents and magnets on solenoids is like that on magnetic needles, some forms of apparatus are based upon this fact, as for example, Sir W. Thomson's siphon recorder.

Very powerful mechanical effects can also be obtained by electro-magnets. Arago was the first to observe that under the influence of an electric current, pieces of soft iron in the vicinity are converted into magnets. If a bar of soft iron be placed in a coil, it is magnetized whilst the current is passing, but the magnetism disappears the moment the current is interrupted. The coil is made of insulated copper-wire, wound spirally a great number of turns round the bar of soft iron.

In practice the soft iron bar is bent into a horse-shoe or other like form. When the current stops, the electro-magnet reverts at once to a neutral condition, if the iron is pure and has been properly annealed.

The power of electro-magnets depends upon:—1st, the intensity of the current; 2nd, the number of turns made by the wire in the coil; 3rd, the nature of the iron and its shape; 4th, the shape and size of the armature. In general, it may be said that, other things being equal, the electro-magnet is more powerful as the diameter of the iron is greater; that the magnetic intensity is proportional to the current, and to the number of turns made by the wire.

The facts stated above will, it is hoped, suffice to make our readers understand the action of the apparatus to be described in the next chapter. We have not considered it desirable to enter into details on the theory of electro-magnetism, but those who desire to pursue this matter may consult some of the already published treatises on electro-magnetism.

CHAPTER V.

TELEGRAPHIC APPARATUS.

Wheatstone and Cooke—Thomson's Mirror Galvanometer—Commutators—
Condensers—Siphon Recorder—Morse Apparatus—Relays—Keys—
Wheatstone's Automatic Apparatus—Hughes' Printing Telegraph—
Duplex Telegraphy—Earth Plates—Lightning Conductors.

IN the historical sketch we have given of the first attempts at telegraphy, it is related how Mr. Cooke, after he had introduced in England a copy of Schilling's telegraph, transformed it—with Wheatstone's co-operation—into an apparatus, first with five needles and five wires, afterwards with only two needles and two line wires. Afterwards, Wheatstone reduced the number of needles to one, requiring only a single line wire. In England this apparatus has remained in use on all the railways and some of the least important postal-telegraph lines.

The "single-needle" instrument is based on the fundamental fact we have explained in the preceding chapter; that is to say, that a magnetized needle, placed in the centre of a coil of wire will be deflected to the right or to the left according to the direction in which the current is sent through the wire. There are two forms of the "single-needle" apparatus; one (fig. 146) with a handle; the other (fig. 148) with two levers or keys. The principles of these apparatus are identical, the only difference is in the manipulation. Fig. 147 shows the apparatus uncovered. A is the receiver. It consists of two coils of silk-covered copper wire placed symmetrically on each side of the magnetic needle, which is placed in their magnetic focus. One end of these coils is in connection with the line, the other with the earth. On the same axle as the magnetic needle, there is fixed an indicator on the outside of the case. The movements of the indicator and needle are limited by two

small ivory studs. When a current passes through the coils, the needle and indicator are deflected, and the direction of that deflection depends entirely upon the way the current passes. Although the coils appear separate, they form in reality but one and the same circuit, as they are both attached to a metallic

FIG. 146

frame which allows one of the coils to act by itself should the other happen to be damaged by lightning.

To make the needle deflect to the right or to the left at will, we only require an arrangement for reversing the direction of the current. An examination of the manipulator will show us how this is to be effected. The wires from the zinc and copper poles of the battery are attached to *z* and *c* respectively. The line wire enters at *A*, and from *B* proceeds a wire connecting with the earth (fig. 149). The arbor *D F* (fig. 150), which

carries the handle, is made of brass, in two parts, D and F, which are separated by insulating material : D is connected with the copper pole, and F with the zinc pole. Two steel springs, p p' , connected respectively with the pieces b b' , put p b into communication with A, that is to say, with the coils, and connect p' b' with B, i.e., with the earth. These two springs press strongly against the part D and F, and thus the continuity of the line is maintained. The F half of the arbor has a projection, m (fig. 147), which rests between the two springs p and p' without touching either of them so long as the handle is at rest. We know that b p and b' p' are in metallic contact. If now the handle is turned to the left, m follows the movement, and by pressing against b (which is in communication with A through p) connects the copper pole with the line ; at the same instant the projection m is turned to the right, and pressing on the spring p' , it puts b' , and therefore B and z into communication ; and thus carries the zinc current into earth. If now the handle is turned to the right, all the movements are reversed ; the projection m' is brought into contact with b

FIG. 147.

and therefore connects the copper with the earth ; whilst m pressing against p sends the zinc current into the line. The current may then be considered as passing through the earth to the coils of the distant station and deviating the needle there in the direction opposite to that in the former case, and then returning through the line wire to A, by which it reaches the zinc of the battery.

In the key form of the apparatus, the currents are sent on a different plan. In the key shown in figs. 151 and 152, z and c , with which the poles of the battery are connected, are strips of metal; E and L represent two stiff metal strips, which, however, can be pressed down by the hand. They are both in contact with z when at rest. One of them is joined to the

FIG. 148.

line wire L , and the other, E , to the earth. If we depress L , it will touch c and complete the circuit, the copper current then passing through the line while z is put to earth. The line and the coils of the distant station will then be traversed by the copper current, which returns through the earth to the z of the battery.

If, on the other hand, the key E be pressed down while L remains in its normal position, the direction of the current is

reversed; the copper of the battery is now put to earth, and the zinc connected with the line; consequently the needle at the distant station is deflected in the opposite direction.

Fig. 152 represents a key on the same plan, which is used with Sir W. Thomson's mirror galvanometer. This figure shows the apparatus in section only, and at c in fig. 153 it is seen in elevation.

The principle of the mirror galvanometer, which is used with submarine cable is the same as that of Wheatstone's single-needle instrument. Fig. 153 shows the general arrange-

FIG. 149.

ment of the apparatus :—A is the galvanometer, *c* the transmitting key, such as we have already described, L the lamp, provided with a tube containing converging lenses, by which the ray of light is made to fall upon the mirror in the galvanometer, whence it is reflected on to the screen R. The small mirror, which is shown of its real size at N S, is hung in a tube that slides through the centre of the galvanometer. It is attached to this tube above and below by a single fibre of cocoon silk. A small magnet is fastened to the back of the mirror; and the directive action of a strong curved magnet at the top of the case normally keeps the mirror parallel to the plane of the apparatus. The light of the lamp, projected on the screen as a spot of light, forms the indicator of the instrument.

The key *c* gives signals to the right and left, and these stand for the points and dashes of the Morse code. The apparatus is sometimes supplemented by a commutator or distributor, not represented in the figure.

By means of this distributor (fig. 154) the line can be alternately put in communication with the receiving instru-

FIG. 150.

FIG. 151.

ment (3) or the transmitting key (1). A passing contact (2) at the same time allows the line to be discharged into the earth. The piece *D* made of copper, turns on an axle by which it may be placed in contact with 1, 2, or 3, as required. It communicates with the binding screw (4), by which it is connected with the line. In the figure, the line and the receiving instrument are connected together. It is sometimes necessary to diminish the range of the movement of the mirror so that the spot of light may not pass off the screen. In such

cases a water resistance is interposed in the receiving circuit. This is formed of two tubes (fig. 155) within which hangs a gutta-percha covered wire terminated by pieces of platinum. According as the wire is raised or lowered, the resistance of the

FIG. 152.

circuit is increased or diminished, and thus the range of the movement of the spot of light can be limited as desired. Some telegraph clerks like the signals very small, while others prefer

FIG. 153.

to have them more ample ; this apparatus enables each to gratify his particular taste.

On long lines it is necessary to interpose a condenser in the circuit, so as to do away with the effects of induction. This condenser is placed either in the circuit of the apparatus itself, or is placed at the beginning of the line itself, which then

continues insulated at each end. The terrestrial currents that tend to pass through it then cease to affect either the transmission or the reception of messages, for they are stopped by the condenser. In this case, the connections of the apparatus are those represented in fig. 156.

The *condenser* or *accumulator* is the name given to an

FIG. 154

apparatus consisting of alternate layers of metallic paper, and paper saturated with wax or paraffin, or films of mica or of gutta-percha arranged so as to form a Leyden-jar of great extent of surface, and so constructed as to have a given electrostatic capacity. a, a_1, a_2, b, b_1, b_2 , fig. 157, are square sheets of tin-foil separated by thin leaves of paper soaked in paraffin or some other insulating substance. The series a, a_1, a_2 , are connected together, and so are the series b, b_1, b_2 . A and B are likewise connected with what may be termed the

inside and outside of this Leyden-jar ; by putting B to earth or connecting it with the pole of the battery, an electro-static charge can be given to A, the quantity of which depends upon the number of cells in the battery and the extent of surface of

FIG. 155.

FIG. 156.

FIG. 157.

the condenser. This last depends upon the number of sheets of the series that are opposed to each other. Condensers may therefore be made of any capacity, giving charges varying from that which a mile of cable is capable of receiving up to that of one of the trans-Atlantic cables. The unit or standard by which these capacities are measured is called the *microfarad*, and a condenser of this capacity takes a charge equal to that

FIG. 158. — The Siphon Recorder.

which would be contained in three nautical miles of submarine cable.

As the signals given by the mirror galvanometer leave no trace, the instrument has the defect of all apparatus that give but temporary indications, and if therefore it is employed with long cables in preference to any other, it is because it is almost the only instrument that will work on these long circuits without disturbance.

Sir W. Thomson's siphon recorder however is used with the long cables of the Eastern Telegraph Co. It may be hoped therefore that the same instrument may some day come into use with the Atlantic cables. In this apparatus, the chief difficulty to overcome, was to obtain distinct marks from a very light body put into rapid movement. This result was obtained by means of a capillary glass-tube, from the end of which a solution of blue aniline is discharged in a very slender stream, by being electrified statically. A little machine, which has been called the *mouse mill*, produces the supply of electricity for this purpose. The siphon is moved by a small coil of fine wire, placed in an intense magnetic field. Powerful electro-magnets constantly traversed by the current from a large battery, magnetize this field. The coil of fine wire moves freely between the poles of the electro-magnet, and round a fixed core of soft iron. It communicates its movements to the siphon by means of silk fibres suitably arranged.

Sir W. Thomson makes his apparatus more effectual and more easy to regulate by using graduated derivations (or shunts) by which the motions of the coil may be reduced. This coil, with its soft iron centre, and the connections with the siphon, &c., forms a system fixed to an insulated freely moveable piece, that can easily be adjusted when necessary. The coil can be regulated in its movements by the torsion of wires, so that a longer or shorter range of motion can be obtained (fig. 158).

The siphon shape would no doubt allow of the flow of liquid to be obtained by simple atmospheric pressure, but in the apparatus we are describing, the ink is expelled by the repulsion of statical electricity produced by a small induction machine, worked by an electro-magnetic engine of novel construction.

The induction apparatus is so made that only the accumu-

lator is used and an electrophorus is dispensed with. The armatures of the *mouse mill* are arranged like the staves of a cask, and they supply the accumulators of the inducing apparatus. The motion of the mill is communicated by an axle and pulleys to the apparatus for unrolling the registering paper. The axle is kept in its place by vertical guides that are moved by the end so as to transmit no vibrations.

A commutator of peculiar form allows the connection of the transmitting and receiving apparatus to be changed, and by means of suitable shunts, the registering apparatus can be made to mark the signals sent as well as the signals received.

Fig. 158 shows the general appearance of the apparatus.

Adjustment of the Paper.—The paper enters on the right and comes under the spring *a* which keeps it stretched; it then passes to the roller *b*, thence to a slightly convex guide-plate *c*, which gives it a vertical direction downwards and brings it immediately under the point of the siphon *tt*, and then it reaches the drawing-off roller *d*. It makes a quarter of a turn on this roller and passes out horizontally to the left. A second roller, *e*, presses the paper sufficiently to cause it to be drawn out by *d*. This roller is pressed by its supports against *d*, and the supports themselves are fixed to a copper frame turning on a strong horizontal rod, *g*.

A lever, placed to right of *g* is pressed downwards by a strong spring, that causes the paper to be seized between the two rollers. This spring can be eased by means of an eccentric turned by the little handle *f*.

To free the paper we must turn the handle *f* to the left; the roller *e* then falls three or four millimetres and leaves the paper, which can then slide easily, and ceases to be unrolled, although the cylinder *d* may continue to turn. If, on the other hand, the handle *f* be turned to the right, the paper is again seized between the two rollers and it goes on unrolling again.

The distance between the paper and the point of the siphon is regulated by turning the screw *i*, which causes the upper part of the apparatus to slide in a groove. The zero line, formed by the continuous flow of the ink, can also be brought to the exact centre of the strip, by means of the screw *H*, which

carries the whole system backwards or forwards on the triangular plate *G*. A uniform passage of the paper between the rollers *d* and *c*, is obtained by turning the screw *k*, which raises or lowers the nearest end of the roller *b*, until a perfect regularity is obtained. The rate at which the paper passes, may be quickened or retarded by changing the line from one pulley to another. The rate of the paper can also be regulated by means of the commutator *x*, which determines the speed of the revolutions of the *mouse mill*.

Adjustment of the siphon and the signal coil.—Siphons are easily made as follows: Take a glass tube one quarter inch in diameter and of a thickness equal to about one-sixth of its diameter; in an ordinary gas-flame heat about three-quarters of an inch of the tube near the middle, turning it round carefully. When the glass is sufficiently soft, withdraw the tube from the flame and draw it out until its diameter is reduced to the size desired. Cut the fine tube thus obtained into lengths of four inches. To make one of these tubes into a siphon, it is only necessary to apply a lighted match at the proper point until the free part has curved down, to be nearly at right angles to the part held in the hand. The tube may also be bent into the shape shown at *E* (fig. 158) leaving the longer branch about two inches long.

The siphon thus prepared is placed in position upon an aluminium saddle *s* (*E*, fig. 158), and fixed with a little wax by a warmed spatula.

To fix or remove the siphon, the piece *m m* (*B*, fig. 158) must be raised. The turn of the siphon *i i* rests on this piece, which has a curved guide of a V shape, allowing the siphon to be moved without disturbing the signal coil. When the siphon is removed from the ink fountain, the warmed spatula is applied to the aluminium saddle; the wax melts and the spoiled siphon can be removed and another put in its place.

To adjust the relative positions of the siphon and the signalling coil.—We must see, first, that the coil is freely suspended round the soft-iron magnetic inducer about which it has to oscillate; second, that all the cocoon silk fibres are sufficiently tight; third, that the normal position of the siphon is vertical.

Adjustments of certain parts are required when the apparatus

is fitted together, but when once this is done, these parts remain unchanged.

The most suitable ink for the siphon is aniline blue, soluble in water. By dissolving in half a glass of water as much of the crystalline substance as will lie on the point of a penknife we obtain a perfectly fluid ink of a fine deep-blue colour. This ink is preferable to any other because it does not get thick or deposit any sediment, and as it can be prepared in small quantities it is very handy.

Adjustment of the electrical mill.—This apparatus is at once an electro-magnetic engine, and an electro-static induction machine. By the former action it brings the paper under the siphon ; by the latter, it electrifies the ink which is projected in a continuous line. With a long cable and a fine siphon this last function is the more important ; whilst with shorter, the arm of the lever need not be so long, and where a greater speed may be attained it is more particularly the former that is required.

If the mill does not turn with sufficient rapidity, the contact piece *x* must be changed, so as to diminish the resistance of the circuit, and this will immediately increase the speed. The adjustments of the spring contact points should be very exact, and the little cups, in which the friction rollers that support the axle work, should be kept full of watchmaker's oil. If, after all these precautions, the mill still turns slowly it will be necessary to increase the power of the battery that works it.

Three of Sir W. Thomson's large surface-cells described in a former chapter are sufficient for the purpose.

The electro-magnetic contact interruptor consists of two platinum points, one of which is fixed, while the other is alternately raised and lowered by a steel spring moved by the segment of the divided wheel. It is easily seen if the platinum points are too far apart, and in that case the electro-magnet will not successively act on the accumulators as long as required, and the result will be a diminution of power ; on the other hand, if the contacts last too long, the electro-magnet will continue to act on the accumulators after they have passed its poles, and will tend thus to retard and stop their movement. The adjustment therefore of this spring is one of the most important points of the apparatus. This can readily be done

by turning the screw that raises or lowers the fixed contact, and when once this has been adjusted it is left undisturbed.

When the ink is not sufficiently electrified although the mill is turning properly and appears to be generating a proper supply of electricity, the rod P must first of all be brought near the plate O. The ordinary distance is from 2 to $3\frac{1}{2}$ inches. A piece of paper is sometimes placed between the rod and the plate to facilitate the electrification of the ink. This depends however upon the hygrometric state of the atmosphere. We must make sure that the apparatus supporting the siphon is perfectly insulated and to make it so, all dust must be removed by a badger-hair brush or by a feather from the silk fibre guides. The piece of ebonite supporting the whole is always covered by a layer of paraffin to keep the insulation perfect. The solid piece of paraffin that supports the rod P and insulates it from the insulated inducer, also requires attention ; for dust may be deposited upon it so that the electricity escapes over its surface. When the mill turns easily but without giving off electricity, it is necessary first to take off the cover and carefully remove the inducer covered with paraffin to see if its insulation is perfect ; then, to see if the four gold contacts properly touch the pieces of copper.

If the mill gives off too much electricity, the siphon, instead of giving a straight line, will vibrate laterally, and the signals will be distorted. The excess of electricity is removed by carrying some off by means of a metallic point placed in contact with the outside of the mill, and directed towards the rod P.

The connections of the siphon recorder are usually made as shown in fig. 161. The current from the line, after having passed through the signal coil, and a properly adjusted shunt, S, returns to earth through a condenser of about 2 or 3 *microfarads* for every hundred miles of cable. A commutator of a novel form (fig. 159) invented by Mr. B. Smith, takes the line current to earth when the handle is turned to the right, and when turned to the left, the current is transmitted. In the intermediate position, shown in the figure, the line wire is directly put to earth to be discharged. In some stations the condenser is placed between the line and the apparatus, and not between the apparatus and the earth as in our design. In these cases the transmitted signals, as well as the received signals, pass

through the condenser, whilst with our arrangement shown in fig. 160, only the received signals affect the condenser. This gives the best results, and experience has shown that in this way the cable and the condenser preserve nearly an equal tension, and thus the transmissions are facilitated.

FIG. 159.

By turning the commutator to the left, the signals given by the transmitting key pass into the line after traversing the apparatus by which they are recorded. A properly adjusted shunt, s, allows only a very small part of the currents for the line to pass into the apparatus.

Thus the apparatus has the advantage of registering the signals that are sent as well as those that are received.

A small commutator *C*, placed next the line, allows the latter to be put to earth in case of a storm, &c.

The number of cells used for transmitting the signals varies according to the length of the cable. Between Marseilles and Malta, a distance of 834 miles, four or five cells are sufficient.

FIG. 160.

On the section between Malta and Alexandria, a distance of 927 miles, eight or 10 cells are used.

Three trough-cells are required to work the *mouse-mill*, and nine suffice to suitably magnetize the series of electro-magnets.

The speed of transmission may reach 25 words per minute, and the signals are well formed and the apparatus is properly adjusted. It is easy to learn to read these signals, and the clerks acquire the power of doing so much quicker than when the mirror signals are used, which being transient and requir-

ing to be written down at once by the clerk, introduce two sources of error.

In some apparatus the silk fibres are suppressed by making the siphon move directly with the coil (fig. 161). Thus the difficulty of electrifying is removed, and the pressure of the atmosphere suffices to give a very distinct line on the paper, if the point of the siphon has been carefully prepared so as not

to stick in the paper. The latter may, moreover, be covered with soapy matter to make it glide more smoothly under the siphon.

Morse's Apparatus. — As Morse's apparatus has been adopted by various European States, and by the American telegraph companies, it has more than any other exercised the ingenuity of mechanics and inventors. Many improvements have been made in it, and a large yet interesting volume might be written on this one subject. We shall however here confine our attention to the apparatus now used in overhead and sub-

FIG. 161.

marine lines, and to the most improved forms of the mechanism.

Vail's apparatus indented a slip of paper by a style with the well-known signals of the Morse code. All the apparatus that are now used print the signals with ink by means of the arrangement shown in fig. 162, where *M* is the manipulator, and *L* the line extending from one office to the other. The line is connected with an electro-magnet *R*. A lever, turning on the pivot *a*, is attached to the soft-iron armature *A* of the electro-magnet, and terminates in a little ink-wheel, *b*, that dips into a vessel of ink *B*. If the slip of paper *P* be continually passing in the direction shown by the arrows; then a depression of the key *M* will connect the battery *c z* with the line at *m*,

the current will traverse the electro-magnet, the armature will be attracted and the motion of the lever bringing the inked wheel into contact with the paper that is passing under *c*, a black mark will be made of a length depending jointly upon the rate at which the paper passes and the interval of time during which the key *M* is depressed. When the key is released the current ceases to pass, the electro-magnet no longer attracts the armature, the spring draws *A* upwards, and the wheel *b* leaves the paper and again dips into the ink. An instantaneous depression of *M* will cause the paper to be marked simply by a dot, while a longer depression will produce a line or dash, and

FIG. 162.

this gives the means of producing the signals of the Morse alphabet.

Fig. 163 shows a complete Morse instrument, as constructed by Siemens of London. Digney's Morse apparatus, shown in fig. 164, was among the first in which the inking arrangement was introduced into the telegraphic service. In this, the inking wheel rotates in a fixed position, and receives its ink from a roll covered with cloth constantly charged with printer's ink. The style of the movable lever connected with the armature brings the paper into contact with the inking wheel, while the current passes ; and the dot and dash signals are made as already explained.

Siemens' apparatus have been most used in England ; and Digney's in France and elsewhere. Some of the latter have been in use in the India Office since 1862. In fig. 164, it will be seen that the roll of paper is contained in a drawer where

it turns on a wooden pivot. This plan was suggested by Stroh, and is better than the old arrangement of a vertical wheel.

FIG. 163.

In the apparatus described above, the current acts directly on the inking system ; but when the line is very long, the

FIG. 164.

current received at the distant station would be too feeble to move the lever. In these cases certain apparatus called relays are resorted to, by which a delicately adjusted arrangement is made to close the circuit of a local battery that acts on the

electro-magnet. Fig. 165 illustrates this system : R is the relay, and $c' z'$ the local battery that it brings into action. When the key m is depressed, contact is made at o , a current is sent into the line and through the key M to the electro-magnet of the relay R and to earth. The attraction of its armature by R puts N into contact with the local battery $z' c'$ and this traverses the local magnet R which brings the inking apparatus into action.

R' may evidently be hundreds of miles away from R, and then L' would be a second line, while the earth would take the place of that part of the circuit between z' and R'.

The relays are so constructed that a very slight current, or a slight increase in the strength of a current, suffices to make

FIG. 164A.

the contacts of the local battery. For example, the relay may be so adjusted that a single unit of current brings it into action; or it may be adjusted so that while it does not act with 100 units of current, it will at once determine the contact when the current reaches 101 units.

Relays are also often made, so that the armature is attracted by the current from only one of the battery poles, and not by the other. In such case the soft iron of the armature is replaced by magnetized steel. In other arrangements that have been contrived, a current in the opposite direction is required to make the lever resume its position.

The best-known form of relay is Siemens' polarized relay (fig. 166). S is the south pole of a tempered steel magnet, the north pole of which, N, terminates in branches to the two cores of the electro-magnet M. Between the upper parts of these cores, the slip A oscillates about its pivot D. The coils are wound in opposite directions round the two branches of the electro-magnet, so that the current in one direction tends to make N a north pole, and N' a south pole, while a current in the opposite direction makes N south, and N' north. Although

FIG. 165.

the piece A D is made of soft iron, it forms a prolongation of the pole S of the magnet, and is therefore magnetized in the same way.

Relays can also be made to transmit positive and negative currents, according as they receive the one or the other current; and the Morse inking apparatus can also be made into a relay for throwing local currents into circuit, instead of marking the paper. The two operations may even be combined. It is in this way that the whole distance from London to Téhéran is worked at one manipulation, with five transferences all working automatically.

Yet, notwithstanding the delicacy of adjustment in the Siemens relays, it often happens, especially with sub-marine cables, that the armature does not respond to a small change of the intensity of the current. It then becomes necessary

often to readjust the apparatus according to the state of the line, and this occasions loss of time and other inconveniences. Brown and Allan have invented a relay, which by a peculiar arrangement of the armature, may be so adjusted as not to be affected by the variations of the current in its circuit. In this relay, the contact is not directly made by the moving slip, which

FIG. 166.

is kept in equilibrium between two opposing spiral springs. When the slip has been attracted to one side by the line current, it tends to revert to its normal position when the current ceases or diminishes ; but if the currents follow one another very rapidly, it is attracted again before it has got completely back ; the charge and discharge of the line are therefore indicated by oscillations of the slip, which, however, remains the more distant from its normal position in proportion to the power and rapidity of succession of the currents.

The contacts are made by a piece oscillating between two stops A, B, fig. 167, placed very close together, and one of these closes the circuit of the local battery. The armature is always free to move, even when the contact-piece touches the stop, or in other words the resting position is very near the contact position.

This apparatus is very quick, and is daily used at Marseilles for communicating with London, with only one transference at Paris. This speed is certainly the highest that can be attained on a telegraphic line of such length. It is never less than

FIG. 167.

thirty words per minute, and it has often reached forty. The relay requires no adjustment, and the less it is meddled with the better it works. A modification of this relay, devised by M. Theiler, also gives excellent results, both with sub-marine and overhead lines.

The manipulator or key used in the Morse apparatus is of a very simple construction, when, as with overhead lines, only one current goes to the formation of a signal. It is represented in fig. 168. A lever B, turning on L, is kept in normal position by the spring R. The line is connected at L, and a current arriving through it passes through A to the receiving apparatus. When the knob C is pressed, the communication is interrupted at A, and the receiving apparatus is put out of circuit; at the

same time contact is made at $\mathcal{E}$ with the battery P , and the current flows through the line to the distant station.

It is often necessary, in very long overhead lines, and with submarine cables, to have recourse to *compensation currents*, which are made to destroy the induction effects of the cable or line. The key shown in fig. 169 is used by the English Post

FIG. 168.

Office, and is very useful on certain overhead and submarine lines. The line wire is connected with 3, the earth, and one end of the relay coil with 7, and the other end with 4. The positive pole of the battery is at c , and the negative at z ; L , L' are two levers insulated from each other and moving on the same axis when the knob is pressed down; s , s''' are two insulated springs connected with z ; s' , s'' two similar springs connected with c . When the key is pressed down, a positive current is transmitted by s' , along the lever L' to the stud o in

contact with s' , and thence to the line through the binding screw 3 ; at the same time a negative current passes through s , along L to the stud q , and by the switch s'' to the earth screw 7. The relay is not affected, for the stud p which is connected with 4 and the other end of the relay is out of circuit, when the commutator s is turned to "Send."

When the key is not pressed down, the levers L and L' rest on s'' and s''' , then a negative current passes from the spring

FIG. 169.

s''' to the lever L' , then by the stud o to the switch s' , and thence through 3 to the line ; at the same time a positive current goes from s'' through the lever L to the switch s' , and by 7 to earth. The line is therefore always charged with a positive or negative current whether the key be depressed or not.

When the commutator s is turned to "Receive," the battery is divided ; the line current enters at 3, the switch s' having been put against the stud p , the current passes to the screw 4, traverses the relay and passes to earth. When the commutator is at "Send," the receiving apparatus is put out of the line

circuit, and the receiving clerk cannot interrupt the transmitting one, until the latter's commutator is put back to "Receive." A galvanometer is always interposed in the line circuit, and this instrument has two separate coils, one connected with the sending, and the other with the receiving circuit, and this enables the transmitting operator to see any interruptions made by his correspondent.

There are many other kinds of key, but we here describe only the two forms that are most used in telegraphy.

Wheatstone's Automatic Apparatus. — Although a good operator is able to transmit more than forty words per minute with a Morse key, this speed is never continuously maintained in practice. The effort cannot long be sustained, and, however expert the operator may be, his signals at this speed are not always clear and well formed. If a machine that would transmit the signals at the highest possible speed were substituted for the hand, there would be the manifest advantage of having clear and perfectly formed signals made by an instrument incapable of fatigue.

Further, although overhead lines are much less liable to induction effects than are submarine or subterranean cables, yet with a rapid succession of signals, a similar inconvenience is experienced. It is only by using alternate currents at each signal, that the speed in overhead lines can be increased. But with the Morse alphabet the limit of speed is soon attained, since the length of the dots and dashes depends upon the *duration* of the currents.

A series of dots can be much more rapidly transmitted than dots and dashes successively, because the currents sent are uniform and charge the line to the same degree ; whereas the dash charges it more strongly and therefore requires a longer time for discharge, or a longer influx of the contrary current to bring it to the neutral state. Besides this unequal effect in the duration of the currents, there is also an important action on the receiving electro-magnet ; for if a current is prolonged the iron is more powerfully magnetized, and therefore requires a longer time to revert to the neutral state. In consequence of this, the signals made with great rapidity become confused, the effect of one current not having ceased before another follows ; so that a dot following a dash might simply appear a

prolongation of the latter, and a dot by itself may fail to appear at all.

The Morse signals can be reproduced by means of currents of uniform duration, by using a polarized armature so adjusted that it remains in the same position, after the contact is broken until an opposite current be sent ; that is to say, so arranged

FIG. 170

that it works only by the effects of the currents. In this system the dot is produced by a very short positive current, immediately followed by an equally short negative current ; whilst the dash is produced by a very short positive current followed by a pause to allow the inking wheel to make a stroke, and then a negative current to detach the armature from the electro-magnet.

By sending into the line very feeble currents during those intervals of time when, in the older system, it used to be left

insulated, we may also compensate the irregularity of the intervals between positive and negative currents, and obtain the greatest possible uniformity in the potential of the line at the beginning of each signal; in this way the first and last currents of a dot or a dash pass directly to the line, and the interpolated or compensating currents act upon it through a resistance that can be varied at will, according to the force required.

A further increase of speed is obtained by interposing a condenser between the line and the receiver; the plates of the condenser are themselves united through a rather large resistance. If a condenser were placed between the line and the automatic manipulator, the speed would be diminished by the signals running together.

By speed is meant the number of perfectly distinct signals that can be transmitted in a given time, and not the interval required for the production of a signal. With Wheatstone's apparatus, the speed is inversely as the distance, and not as the square of the distance.

The following is a description of Wheatstone's automatic system as used in England and France :—

The strip of paper is prepared by an apparatus (fig. 170) called the perforator, consisting of three levers, one of which produces two perforations in a line with each other to form a dot, while another makes two perforations diagonally across the strip, which form the dash. The third lever gives a continuous series of smaller perforations in the middle of the strip, and thus produces a kind of rack by which a toothed wheel carries the paper along when the strip is placed in the automatic transmitter. The central perforations are made at the same time as those which mark the dots and dashes; the centre lever advances the part of the paper answering to the blank spaces.

The transmitter is put in motion by a weight, the descent of which may be adjusted to send from 20 to 120 words per minute. The perforated paper is carried along by a toothed disc moved by clock-work, the teeth engaging the central perforations against a friction roller.

The principle according to which the alternating currents are produced is indicated by fig. 171. Let *D* be a metal disc divided into two parts insulated from each other, and carrying

fixed metal pegs *a* and *b*. Let us suppose the part in which *b* is fixed to be in connection with the line, while *a* communicates with the earth. Suppose, also, that the two battery levers are pressed against these pegs by the springs *s s'*, one of the levers *c* being connected with the copper pole of the battery *B* and the other *z* with the zinc pole. It is evident that, in the first

FIG. 171.

case, the negative current enters the line, whilst in the other case it is the positive current. Therefore, if the disc *D* can oscillate between these positions in a regular and continuous manner, it will send into the line a series of alternate currents, which will show themselves by a series of dots in the receiving instrument at the other end of the line.

If, however, the line or the earth connection be temporarily interrupted before the disc takes the second position, the inverse current will not be sent, and a dash will appear at the transmitting apparatus instead of two dots. The use of the perforated paper is to regulate the movement of the transmitter.

so as to produce this interruption at the right instant, and cause dots or dashes to appear as may be required.

We know how the perforated strip is carried forward. Two rods *M* and *S* are fixed at the ends of the levers *A* and *B*, which are themselves connected with the frame of the apparatus, so as to admit of their turning ; but they are kept in position by the springs *s* and *s'*. The rods *M* and *S* either pass through the perforations in the strip of paper, or are stopped in their upward movement if a perforation is not opposite to them.

FIG. 172.

In fig. 172, we see the rod passed through one of the perforations. *R* is a rocking lever of ebonite, in which are fixed two metal studs 1 and 2 ; this lever is kept in a constant state of regular oscillation by the wheelwork of the apparatus. These studs are in contact with arms of the levers *A* and *B*, which thus are made to oscillate in unison with *R*. At the lower part of the lever *A* is fixed a rod *H*, and a smaller one *H'* is attached to the upper part of *B*. The ends of these rods move freely through projections from the divided disc *D*. The collars *K* and *K'* by pushing *P* and *P'* make the disc oscillate in perfect accord with *R*. The lever *C* is provided with a screw, which, when the disc is in the middle of its oscillatory movement, abuts against a small piece of ebonite fixed in *Z*, which prevents the battery being thrown into short circuit. The little roller *E* completes the part begun by *K* and *K'*, and keeps the disc in its

position until it is reversed by the thrusts of κ and κ' . Thus the lever R causes the rods S and M to regularly move up and down, by making the arms A and B oscillate; so, while these rods continue in action, the disc D vibrates backwards and forwards, carrying with it the levers C and Z .

The stud 1 of the lever R is in communication with the earth, and 2 with one of the halves of the disc D , the other

FIG. 173.

half of which communicates with the line. When the strip of paper is not in its place, these studs are in constant and uninterrupted contact with the arms of the lever A and B , which are plated with platinum and metallicly connected with the frame of the apparatus s and s' , and thus the circuit is completed, and transmits a series of reversed currents that produce dots at the receiving end of the line.

At the places where the strip is not perforated, it limits the play of the rods, and the elbow levers A and B no longer follow the studs to the extent of their motion: the disc D ceases to move; and the communication being thus interrupted, no

current is sent into the line. Where the paper is perforated, a dot gives a reversed current at each oscillation, and a dash at each second oscillation. The rod *M* passes through the upper perforation, and the reversed current passes to the line.

The transmitter can be adjusted to work at the maximum speed of 130 words; but this does not mark the absolute speed at which the apparatus can work. This speed is rather deter-

FIG. 174.

mined by the receiving capacity of the registering apparatus, and this capacity is limited, not only by the mechanical inertia of the apparatus itself, but also by what may be termed the inertia of the electro-magnet. Thus the speed of transmission is limited by the capacity of the receiver.

This last is a very sensitive Morse printer. The paper passes above the printing disc with a uniform velocity, and the apparatus is so arranged that it can be adjusted to print at any speed from between 20 and 130 words per minute. The disc is fixed on an axle moved by clockwork, and turns partly in the groove of a roller of larger diameter, which dips into

the ink-well. This second roller draws up the ink by capillary attraction, and charges the inking disc without friction. The axle *a* (fig. 174) of this is moved by the armatures T and T', which are of soft iron kept magnetized by the permanent magnet N S. Fig. 174 shows how these can be adjusted. The arrangement is such, that when they are once attracted by a current, however short, traversing the electro-magnet E, they remain in their places. They only revert to their normal position by the passage of a current oppositely directed to that which has attracted them. When, therefore, the armatures and the axle *a* are set in motion, the printing disc is brought into contact with the paper and marks it with a line until the opposite current arrives. A dot is produced by a momentary current, followed instantly by a very brief inverse current. A dash is produced by a short current followed by an inverse current arriving after an interval of time. Thus for each signal, two currents must be sent; these currents must be in opposite directions, and separated from each other by different intervals of time, and the perforated paper determines the intervals separating the opposite currents. We trust that the action of the apparatus will now be understood.

Figure 175 shows the general arrangement of the apparatus as established at one of the terminal stations. It comprises, attached to the transmitter, a commutator, of the action of which we have not hitherto spoken. It is here shown in the position it assumes when the apparatus is ready for the reception of the signals. The diagram shows also a key (*clef*) for double currents which may be put into circuit by means of the commutator, to signal by hand when the transmitter is not in use. A galvanometer indicates the passage of the currents.

The receiver (*récepteur*) is also provided with a commutator which throws a sounder (*parleur*) into the local circuit when the receiver is stopped. This sounder serves as a call, and when necessary may act as a receiver for signals sent by a key. When the receiver is in motion, the sounder is thrown out of circuit. The local circuit is completed by the electro-magnet of the receiver, which thus acts as a relay, or as a direct printer.

The figure shows the transmitter in a neutral position, as it is when no current is being sent into the line, and the lever *c* is in position to form the short circuit of the battery. R.V. is

FIG. 175.

a variable resistance apparatus to prevent false currents from entering the receiver.

Automatic apparatus are used on nearly all the great European lines. It is evident that the principal advantage of an automatic system consists, not only in its great exactness, but also in the increased speed of transmission. The average speed may reach seventy words per minute, that is to say, a wire will convey twice as many words with a Wheatstone as with a Morse transmitter. But the former is more expensive in working, for when it is in constant use, two clerks are required to work the perforators, another to adjust the apparatus, and there must be three writers at each end.

The despatches are perforated and sent in sets of five, and each must therefore wait for the perforation, again for its turn in the set, and also its transcription at the receiving station. These are all so many causes of delay that there is no economy in employing the automatic system on short lines. It is therefore used only on long important lines.

Hughes' printing telegraph.—This apparatus differs from all others in this respect, that the action is principally produced by machinery, the electric part being confined to the transmission of a brief current when types set on a wheel are in the required position. A single electric impulse then suffices to print a letter in ordinary type. The receiving and transmitting apparatus are identical, and they are manipulated on a key-board provided with as many keys as there are letters or signs to be printed. Arranged in a circle are a set of pins each connected with one of the keys; in the centre of the pins revolves an axle carrying on a projecting arm the “chariot” which sweeps round the circle formed by the pins, without, however, touching them, so long as they remain in their normal position. But when one of the keys is pressed, the corresponding pin is raised; and the “chariot,” by touching it in passing, is caused to make a contact which sends into the line a current that passes through the electro-magnets of the sending and the receiving instruments.

The type-wheel is carried round on an axle engaged with that which carries the “chariot.” But the type-wheel is so arranged that it can, when required, be stopped or adjusted without suspending the general movement. When the “chariot”

FIG. 176.

and type wheel are properly adjusted, a current is sent through the line by a touch of the key at the very moment when the corresponding letter is in front of the paper, and the paper being at the same time raised up to that letter by a movement produced by the current, receives its impression.

There is an arrangement for regulating the speed of rotation, and the errors that may be caused by a difference of speed in sending and receiving apparatus are rectified by a wheel called the "correcting-wheel."

The current prints the letters in this way:—A hollow shaft carrying three cams is fitted on the axle of a wheel that is geared with the axle of the type-wheel. This hollow shaft is not carried round by the axle that passes through it, except when the two are joined by a click brought into action by the current. Thereupon the axle and hollow shaft turn round together, and the following results are produced by the operation of the cams:—

- 1°. The first cam corrects the position of the type-wheel.
- 2°. The second cam presses the paper against the type.
- 3°. The third cam carries the paper forward.

The connection between the hollow shaft and the axle is then broken, and the shaft stops. A fourth cam replaces the armature on the electro-magnet, and the apparatus is then ready to receive the next signal.

The electric action, although simple, presents some peculiarities. The electro-magnet has two soft iron cores covered with fine wire, and each of these cores rests on a pole of a permanent magnet (fig. 177). The armature is also made of soft iron, and when it is placed on the electro-magnet, it is attracted and retained by the polarity induced in the cores by magnetism. A spring adjustable by means of a screw tends constantly to free the armature. If a current traverse the coils in such a direction as to produce a polarity opposite to that induced by the permanent magnet, the armature will be separated, and as soon as that happens it will leave the cores abruptly with sufficient force to liberate a detent. The armature is afterwards brought back to its place by the action of the wheels.

The attraction between the cores and the armature is regulated by a small bar of soft iron placed between the poles of the permanent magnet. This arrangement makes the appa-

ratus very sensitive. Let us suppose that the magnetization produced by the cores represents a force of 3 ounces, and that the opposing spring has a force of $2\frac{3}{4}$ ounces. A contrary polarity of $\frac{1}{4}$ ounce would therefore suffice to liberate the armature, which would quit the cores with its whole force of $2\frac{3}{4}$ ounces. And as it is replaced in position by the wheel-work, the spring acting upon it may have much tension, since that tension has not to be overcome by the current. As soon as the armature is raised, the coils are placed in short circuit, and the current received passes directly to the earth. Thus suppose that 100 parts of current are received, if 5 parts suffice to detach the armature, the excess passes immediately to the earth without affecting the coils.

When the armature is replaced in its position by the wheel-work, an extra current is produced in the same direction as the received current. The effect of this is the same as if a new current had been sent by one of the keys, and when the resistance of the line is small a continuous action of the armature and the successive printing of several letters might be produced. The formation of this current is prevented by interrupting the circuit of the electro-magnet, by means of the cam shaft immediately

it begins to turn, so that at the instant the armature is put back in its place, there is no circuit for the extra current.

Hughes' apparatus is much used in Europe, and particularly in France, where the instrumental skill of M. Froment has brought it to a high state of perfection. It is certainly the favourite apparatus of the French telegraphic service. On the other hand, in spite of its English origin, it has found no favour in England, where indeed it has been almost entirely given up.

On account of its very rapid transmission, this apparatus has been adopted on the busiest lines. Its working power is great, for it easily sends and prints fifty or sixty messages

FIG. 177.

an hour. On account of the nature of the apparatus, it requires the services of a skilled mechanic at the places where it is used, but as it is used only on the great lines, such mechanics abound in cities like Paris, Lyons, and Marseilles.

A form of telegraph apparatus that in America has superseded every other non-recording instrument, and in England is now largely used by the Post Office instead of the Morse instrument, may here be particularly mentioned. The principle of it is indicated on a preceding page, and even a form of the apparatus described, as the reader will find by referring to the tenth and eleventh paragraphs of Chapter II., Part I., pages 25 and 26. The simplest form of the instrument consists of an electro-magnet through which the line or the relay currents pass. The armature of the electro-magnet is attached to a metallic bar that oscillates on a pivot. A spring causes the farther extremity of the bar to press against an adjustable peg, and in this position the armature is a little above the iron core of the electro-magnet. The moment the current passes the armature is attracted, the action of the spring is overcome, and the bar turns until it strikes, with a sharp click, another metallic point which is so adjusted that the armature is then not quite in contact with the magnetized iron bar. When the current ceases, the spring again brings back the bar into contact with the upper peg, with a sound which in general is readily distinguishable from the former one, or may easily be made so, and which the ear of the telegraph operator recognizes as the end of the signal, that is, the instant when the contact is broken at the transmitting key. It is the varying length of the contacts forming the dash and dot of the Morse alphabet, that are read by the sounds, almost as fast as the clerk can write the message down in words. There are, of course, various modifications of the "sounder," for the purpose of re-inforcing the sound, &c. The advantages of the instrument are its comparatively small cost, which is less than one-third of that of the Morse recorder; the smaller charges for maintaining in working order; and lastly—a matter of great importance in practical telegraphy—its more rapid rate of working, for more words can be transmitted by it than by any other form of telegraphic instrument.

Duplex Telegraphy.—Our readers must be cautioned against the common mistake of supposing that duplex telegraphy consists in employing novel apparatus. It is, on the contrary, applicable to all the instruments we have described, and is the result merely of a particular mode of operating, which places the receiving apparatus in a state of unstable equilibrium, when it becomes sensitive to variations of currents from opposed stations. As this idea appears somewhat abstract and difficult to comprehend, we shall compare the simplest telegraphic circuit with the duplex communications. If the reader will turn back to figure 168, he will see that the Morse key puts the battery out of circuit when receiving, leaving only

FIG. 178.

the receiving apparatus in connection with the line as the signals arrive from the distant stations; whilst, when the key is in use transmitting, the communication is cut between the receiving apparatus and the line, and the latter is put into circuit with the battery.

In the duplex system, matters are differently arranged: during the transmission, as in the receiving of messages, the battery current of the stations always passes through the coils of the receiving apparatus; it should, however, be understood that the coils of this apparatus must be so constructed as not to be affected by the passing-out current, but only by that which arises from signals made at the station in correspondence. Let us see how this result is obtained.

A B, in fig. 178, represents the line; A is the station from which a message is sent, B the station at which it is to be received. At A *c* z is the battery of which the copper pole is

in contact with the key, while the other pole is connected with the earth. The lever of the key is connected with the line through the receiving apparatus, but this receiving apparatus is arranged in a peculiar manner, for instead of its being surrounded by a single circuit, it has two surrounding the needle in opposite directions, so that if the same current passes through these two circuits simultaneously, no effect will be produced on the needle. One of these portions of the circuit is indicated in the diagram by a full line, and the other by a dotted line. Let us suppose that contact is made with the battery through the key; the current beginning at *b* has two circuits open for it; one (full line in diagram) carries it through the telegraph line, the other (dotted line) through a resistance (marked *ligne artific.*) takes it to the earth. It therefore divides into two parts, one of which will surround the needle of the receiving apparatus in one direction, and the other in the opposite direction. If these two currents are not equal, the needle will be deflected every time the key makes the battery contact: if, on the other hand, they are equal, the needle will remain at rest whatever number of battery contacts be made by the key. Let this be well understood, for it is the principle of the whole system. The operator at A must therefore so arrange the circuit of his receiving instrument that when he sends the line signals through his own receiving apparatus this shall remain entirely unaffected, though it is free to receive and mark signals made at B. This result can be obtained only by equalizing the circuits, that is to say, by introducing into the second circuit an "artificial line" equal or very nearly so to the real line, in all its effects on the currents. We have seen that at the point *b*, the current finds two paths, one by the circuit of the real line and the other through the artificial line to the earth. If the resistances and retardations of the circuits are equal, the whole current of the battery will divide itself at *b* into two equal parts; and we have seen how the operator at either station might send signals to his correspondent through his own apparatus without making the latter move, while yet free to receive signals from the correspondent station.

Let us see how it happens that these signals can be received from B at the same time that A is sending to that station. Let

us suppose that the operator at B has arranged the connections of his apparatus of battery, artificial line and key, under conditions absolutely identical with those at A, so that when he sends to A, his own apparatus is not affected. If now, B is sending a message at the same time as A also sends his current, B makes a battery contact at the same time as A, and the result is that no current traverses the line. A stops, so to say, B's current, and similarly B stops A's current, for they use equal batteries and the two currents balance each other. But it is precisely by having the power of annulling each other's currents, that A and B have the control of the apparatus opposed to them. For so long as the currents from A pass freely through the apparatus there, the one into the artificial and the other into the real line, this apparatus remains

FIG. 179.

stationary ; but when the line current is opposed, the balance of the two circuits is destroyed, and the current from A which passes through the dotted circuit to the earth moves the needle and produces a signal. B, therefore, has the power of stopping the current which A sends into the line ; and consequently can produce signals on A's apparatus without disturbing the balance of his own. The like is true of A's power over the apparatus at B.

We shall endeavour to make this still clearer by an illustration taken from the flow of a liquid. Let us suppose that fig. 179 represents a peculiar arrangement of water-pipes, in which A and B are turbines. If water under pressure (which may be taken as corresponding with the electro-motive force) passes from *b* into A, a part will flow on one side of the turbine into L and another part on the other side into the pipe A L. If the section and resistances of the two pipes are equal, half the water will flow on one side and the other half on the other, so that the turbine, acted on by equal and opposite forces, will

remain at rest. But the current of water passing through *L* can cause the turbine *B* to revolve, unless another current of equal pressure enters *B*, in which case all the water passing into *A* must find exit through *A L*, and the turbine will then turn. We see, therefore, that by admitting and stopping the water at *B* we can control the movements of the turbine *A*; and by like means *B* can at the same time be controlled at *A*.

The duplex system that we have just described is called the "differential method" because the coils of the apparatus are wound differentially, that is to say, in opposed directions, so

FIG. 180.

that combinations may be obtained on each coil separately, or in the two coils together, or by opposing their effects on the needle. Apparatus of this kind are much used in testing the electrical resistances of the line and batteries, but it is unnecessary to here give a detailed description of them.

Wheatstone's bridge supplies another practical mode of making the telegraph duplex, by placing an ordinary receiving apparatus in the bridge of the balance known by that name. It is necessary only to put the two ends of the common needle apparatus in contact with the real and the artificial line respectively (fig. 180). The branches in which the current is divided are here quite separate from the receiving apparatus. The rest of the connections are precisely the same as in the former case.

The current coming from the key is here divided into one portion that passes through the upper branch a , and thence by the line L to the earth at the distant station, and into another portion that traverses the lower branch b , to reach the earth through the artificial line AL . It is evident that perfect equality in the two branches a and b , is required to leave the needle motionless. The artificial line in this case, as in the former, must be identical with the real line in all its electrical conditions. The same phenomena attend the transmission of signals as we have already described in the former instance.

The duplex system may therefore be defined by saying that it consists in sending two messages simultaneously between stations connected by a single wire. We must get rid of the notion of the messages passing each other in the wire, or that anything passes in opposite directions. It will be seen by what we have stated above that such is not the case. The problem has been practically and elegantly solved by so connecting up ordinary apparatus that the currents at each extremity of the line are opposed to each other when required. The whole duplex system depends, then, on the particular action of certain apparatus that have long been known.

We have seen that it is essential that the artificial line should be the equivalent of the real line in everything by which the current is affected. In short lines it is sufficient to balance the resistance of the line wire by a resistance coil of equal value. But it is a different matter with long lines (such, for example, as exceed 250 miles in length), in which the effects of induction come into operation. In this case there must be added to the circuit of the artificial line condensers, or other similar apparatus, that give rise to sudden charges of static electricity. When a great line is charged with electricity, the inductive action of the earth adds a static charge, which, at the first instant augments the dynamical charge resulting from the battery current. In like manner, a statical discharge takes place when the line is discharged of its dynamical electricity. These statical charges and discharges show themselves in the apparatus as momentary currents, and they cause vibrations or jerks of the indicator of the receiving apparatus that interfere with the slower movements constituting the signals. The remedy is to give the artificial line a static capacity equal to

that of the real line, and thus the vibrations caused by the discharge of the real line are counteracted by those of the artificial line. The latter must therefore compensate at once the statical and the dynamical effects of the currents.

In submarine cables the induction effects are somewhat complicated, and the jerks caused by the charges were, for a long time, an obstacle to the application of the duplex system on great lines. In addition to the induction effects, there occur with these cables certain retardations and modifications of the current that could not easily be reproduced in the artificial lines. A combination of condensers and rheostats, uniformly distributed, proves insufficient for submarine lines of great length. In fact, the current must not only traverse the artificial line in the same way that it passes through the real line, but it must also keep the same form and intensity in both circuits, or, in other words, travel from end to end of the two circuits like a single undulation. The difficulty of balancing a cable and an artificial line increases more rapidly than in proportion to the length of the former. The importance of these phenomena was perceived as early as 1855 by M. de Sauty, who then used a condenser to compensate the induction effects in experiments carried on between London and Birmingham by the differential method of Siemens. When, in 1868, Stearns took up the subject afresh, he experienced the same difficulties, and on the long American land-lines he surmounted them only by combining condensers with resistances. Yet on land lines, the apparatus does not work in conformity with the capacities of the lines ; whilst, with cables, Sir W. Thomson's delicate apparatus, the mirror galvanometer and the siphon recorder that are so generally used, respond to much feebler currents than those required to form the signals in land lines. The balancing of the duplex apparatus does not require to be so delicate for land lines as for cables.

Experiments made by Dr. Alexander Muirhead and Mr. Herbert have shown that currents enter the cables by a certain kind of undulation, as it were, and it is necessary to imitate in the artificial line all the phenomena of the current from the beginning. Guided by these observations, and embodying the principles arrived at by his brother, John Muirhead obtained a patent in October, 1874, for the artificial line that forms the

base of their system of duplex telegraphy as applied to submarine cables. Since that period the system has been developed and applied by Messrs. Muirhead & Taylor. All the cables of the *Eastern Telegraph Co.* between England, Marseilles, and Bombay have been duplexed on this system. The same has been done with the *United States Direct* cable. The first cable that was thus duplexed was that between Marseilles and Bona in 1875 ; and the system has lately been applied to the Vigo cable.

The system requires a new artificial line, a model of the cable itself; then various adjustments to give the commencement of the artificial line the greatest possible resemblance to the commencement of the cable. This was accomplished in a

FIG. 181.

general manner by giving the artificial line the form of a continuous inducer of uniform capacity throughout its whole length. This may be called the "inductive resistance." It is produced by means of two strips of tin-foil separated from each other by paper charged with paraffin. One of these strips constitutes the conducting circuit of the artificial line ; the other is the external inductive part, and communicates with the earth. This arrangement is shown in fig. 181, representing a part of the artificial cable. The conducting strip is continuous ; but the binding screws, R, are fixed at intervals, and resistances may be thrown in. The strips, or rather groups of inductive strips, are, it must be remembered, separated from each other ; but each group is connected with its own binding-screw, and these are all connected with the earth. Each pair of screws, R, combined with the corresponding capacity C opposite, thus forms an element of a series each member of which is equivalent to about ten nautical miles of the real cable. This method of construction gives us an artificial cable having the same resistance per unit of capacity as the real cable that has to be duplexed.

In fig. 182 is shown the arrangement of the apparatus used at Marseilles for duplexing the cable between Marseilles and Malta. This cable is the simpler example of balance as obtained by the Muirhead system. From Marseilles the cable, which is 826 nautical miles in length, traverses the Mediterranean to Bona, before proceeding eastward to Malta. The system consists in a Wheatstone's bridge combined with an artificial cable in which many of the inducing layers are omitted, the conductor of the artificial line passing to earth through a resistance of 7,000 ohms.

For the cable between Aden and Bombay, which is 1,817 nautical miles long, the balance is established at Aden with $s = 1.23$ microfarad, $r = 0$, $r^2 = 0$, $r^3 = 210,000$ at a point in the

FIG. 182.

artificial cable answering to a distance of 250 miles from Aden; r^4 and $r^5 = \text{infinity}$. The proportion of the artificial to the real line is as three to four, and the resistances of the arms of the balance are respectively 2,000 and 2,030. The total resistance of the real line is 11,827 ohms, and its capacity 656 microfarads.

These two cables work with a Thomson's siphon recorder, the delicacy of which enables the balance to be made with more readiness than the mirror galvanometer. The rapid succession of currents gives rise to slow oscillations as the waves of electricity are formed in the line, and superimposed on these are the set of individual signals in the form of greater oscillations. The coil of the recorder is less sensitive than the galvanometer mirror to these undulations, and consequently the zero of the recorder is less easily affected than that of the galvanometer. In the mirror the displacement of the zero is apt to be mistaken for signals, because the luminous spot travels in the same straight line right and left, whilst the displacement of the zero of the recorder is transverse to the line of signals. More than this, the mirror signals are

The *quadruplex* system consists in again duplexing the system by which two despatches are simultaneously sent in one direction. Stark, of Vienna, had solved this problem by 1855, for by means of two batteries and two keys properly arranged, he obtained a differential magnetic effect on the two relays at the receiving station, by means of which two independent communications could be sent in the same direction simultaneously. We do not propose to describe this system at length, or the similar one of Gerrit Smith, which Muirhead and Winter have succeeded in duplexing so as to constitute a quadruplex that practically works well. Other quadruplex systems have been in use, since 1874, on sixty lines of the *Western Union Telegraph Co.* in the United States. In France and England, great efforts have been made to keep abreast of the Americans in the rapid progress they are making in such applications of electricity.

Accessory Apparatus.—This kind of apparatus is required at all telegraph offices ; but we cannot here give an account of it all. The line wires usually reach the office through a distributor or commutator, like those shown in fig. 184. This commutator is made of strips of copper, crossing each other at right angles, and provided with a circular opening at their points of intersection, so that by inserting metallic pegs, P, a connection is made between the upper and lower strips. The pegs must fit in tightly, both above and below, to ensure the contacts. It will be understood that any one of the four line wires, L^1 , L^2 , L^3 , and L^4 , which reach the lower strips of our apparatus, can at will be connected with any one of the lines that proceed from the upper strips, A^1 , A^2 , A^3 , A^4 . Apparatus of this kind is also employed for connecting up the battery wires, and one of the binding screws is commonly kept for a wire that makes an earth connection.

Earth Plates.—The wires that make the earth connections at telegraphic offices require some attention, for a bad connection may cause much trouble. When the ground is damp, it is only necessary to bury in it a large metallic plate, to which a strand of iron wires from the office is attached. But if the soil be very dry, the earth connection must be made in a well or neighbouring stream. There are instances in which it has been found necessary to carry the earth wire a great distance

to reach suitable ground. In the island of Saint-Pierre Miquelon, the earth connection had to be made some distance out at sea. Ordinary methods proved insufficient, and the mirror apparatus of one station of the Brest cable showed the Morse signals of an American cable belonging to a different company. This was in consequence of an inductive action, arising from the general dryness of the soil of the island.

FIG. 184.

At places where there are submarine cables, no better earth connection than that provided by the outer metallic sheathing can be found anywhere. For these wires are in contact with sea and land throughout their whole length, and they form what may be called a return line for the currents. At railway stations, an excellent earth connection is found in the rails.

Lightning Conductors.—Thunderstorms and atmospheric electricity would often destroy telegraphic apparatus if they

were not protected by lightning conductors. These act by conveying to the earth charges of atmospheric electricity which would otherwise injure the wires and the apparatus.

The simplest method of doing this was invented by Steinheil, and is in use in Belgium and Germany. As improved by Messrs. Siemens, it consists merely of two metallic plates fixed to a plank, and insulated from each other by pieces of ebonite at the four corners. A thin stratum of air is thus interposed between the plates, the upper one of which is part of the line current; while the lower one has an earth connection. Fig. 185

FIG. 185.

gives a perspective view of the arrangement, which is much used by submarine telegraph companies. Over the cast-iron earth-plate *a*, two other smaller plates of the same metal are placed, but without being in contact with it. These plates have screws for fixing the wires. At *ff'* the underground wires are attached; at *F, F'*, the submarine lines. The screw *g* is used for the earth wire. The upper plates are maintained in their position by pegs, *cc*, *dd*, covered with ebonite. The atmospheric electricity reaching the upper plate passes directly to the earth-plate. To facilitate the discharge, the plates are situated in directions at right angles to each other.

Lightning will fuse very fine wires that offer much resistance to its passage, and it is precisely against this accident happening to the fine wires of telegraph apparatus that these pre-

cautions are taken. Sir Charles Bright has contrived a protective apparatus founded on this very effect. It is represented in fig. 186, and consists of a series of wires, stretched between two metallic supports, which are furnished also with sets of points. Two other supports have points very close to the former, and

are connected with the earth through E. The line wire L is connected to the left-hand support, and the apparatus is joined up through C, with a rod that slides in a guide at B. If a discharge of atmospheric electricity melts the first wire, the rod A B drops by its own weight; but, stopped by the projection D, it comes into contact with the second wire. The

FIG. 186.

line is not therefore interrupted, and the original arrangement is re-established, so that the apparatus is ready to act again in protecting the line. This apparatus allows the line currents to pass until all the stretched wires have been successively melted. A then drops upon E, and the line is put to earth, whereupon it becomes necessary to renew the fine wires. This protector possesses the advantages of keeping for a long time in working order without requiring attention, and of effectually securing the safety of the apparatus or cable to which it is applied.

CHAPTER VI.

POSITION OF FAULTS.

Derangements — Faults — The Mirror Galvanometer — Resistance Boxes —
Methods of finding the position of Faults.

THE derangements of the apparatus that occur in telegraphic offices are easily and certainly detected by experienced employés. Their intimate knowledge of the connections, paths of the currents, etc., soon teaches them the seat and cause of the derangement. The receiving and transmitting apparatus are moreover also always accompanied by a magnetic needle or galvanometer for indicating the passage of the currents, and this at once shows whether the fault is in the office or in the line. When this magnetic needle is not deflected while the currents should be passing in into the line, the defect is in the galvanometer itself, in the battery, or in the wires within the office. It rarely happens that the apparatus in a well-kept office gets out of order.

The adjustment of the complicated apparatus is usually made by the superintendent of the line, and the subordinate official seldom assumes the responsibility of a possible stoppage of communication.

Whenever the communications are interrupted outside, the cause is a fault in the line. These faults are due to (1) bad insulation; (2) to excessive resistance caused by a bad joint, or a solution of continuity in the conductor; or (3) finally to two wires coming into contact and thus confusing the several signals.

Bad insulation in overhead lines is generally caused by broken or soiled insulators, or by the wire touching a tree or other object, by which a ground connection is made. When bad insulators are used, the defect may extend over a considerable length of the line, whilst contacts of the wire can scarcely occur except at a few detached points. In each case

the amount of the loss may be determined by electrical measurements, and if there be only one defective point, its position in the line can be fixed by the same methods. In submarine cables the defective insulation can be due only to a loss of current at one or more points in the insulating covering. The second condition (excessive resistance or want of continuity in the conductor) implies a breakage of the wire, either in the external line or in the internal office wires, or perhaps in the earth connection. In many cases it is possible to fix the position of the rupture of the line. This usually causes a loss of current to the earth, for in overhead lines the wire falls to the ground; and commonly when the conductor of a cable breaks, it is because something has divided the cable itself. The third accident (contact) is very frequent in overhead lines. When the contact is metallic the position of the fault can be fixed easily.

The tests by which the positions of telegraph faults are determined are always made by means of delicate galvanometers. Such faults are more easily found in cables than in overhead lines, because the insulation of the uninjured part of the cable is usually better in the former. In an overhead line several faults may occur at the same time, and this causes the indications to be more uncertain and frequently incorrect. But by the constant inspection of the overhead lines, visible defects are quickly removed, and thus the uncertainty of determination in the position of other faults is obviated.

The following apparatus are used in testing for the position of faults; these tests being particularly applicable to submarine lines and used for overhead lines in a similar manner. Fig. 187 shows Thomson's mirror galvanometer, which consists of two superposed circular coils, each having two diamagnetic copper frames, so fitted to each other as to leave a groove in their vertical axes, and also a cylindrical opening in their centres. On these coils is wound a very fine wire made of an alloy of copper and silver and covered with silk. A very small and extremely light magnet is fixed to the back of a small circular mirror, which receives and reflects a beam of light through the small circular opening in the upper coil. The total weight of the mirror and magnet does not exceed two grains. These are attached to a light rod of aluminium,

which is carried down into the centre of the lower coil, where it carries a second small magnet placed astatically to the former. Perpendicular to this magnet, in the horizontal axis of the lower coil two discs of mica are fixed to the aluminium rod, so that they may render the movements steady by their resistance to the air.

The slender aluminium stem to which the whole mobile system is attached, is suspended to the upper part of the apparatus by a very fine silk fibre, in the very centre of the

FIG. 187.

apparatus. There are levelling screws in the stand, so that the magnets can be adjusted for free movement, the correct position being indicated by a spirit-level.

The rays reflected from the mirror are brought to a focus either by a convex lens or by the concavity of the little mirror. These rays proceed from a lamp 30 inches distant, and passing through a vertical slit at the centre of the graduated scale, are reflected by the mirror and form an image of the slit upon the scale. This image moves from right to left according to the deflection of the magnet, and as the angle through which it moves is double that of the mirror, the effect is equal to a weightless index nearly 5 feet long, so that the slightest deflections of the magnet are readily perceptible. And further, as a very small deflection ranges over the whole scale, the number

of divisions of the latter represents the intensity of the current.

A curved magnet attached to an upright copper rod that rises above the apparatus, and can be placed at any height on this rod, gives the means of counterbalancing the terrestrial magnetism so as to augment the sensitiveness of the apparatus as required. The upright rod is turned round by an endless screw engaging a wheel attached to the rod, so that the spot of light can be exactly adjusted to the zero of the graduated scale.

This apparatus is not only very accurate, but it is so easily and conveniently used in the tests to which the insulating materials of cables and its adjuncts are subjected, that its employment is now nearly universal.

Let us suppose that a conductor, otherwise well insulated, has a fault at B (fig. 188) at a distance from the station A. If the contact of B with earth is perfect and has no sensible resistance, it will be sufficient in order to find the distance A B to measure the resistance of the length A B, and divide this resistance by that of the unit of length. This measurement may be effected by Wheatstone's bridge as shown in the figure. D A and D F are the two branches of the balance, F E is a box containing variable and adjustable resistances (the box as actually used is exhibited in fig. 189) and Z C is the battery which is thrown into action by the key P. If A D is one-tenth of D F, and the pegs taken from the box between F and E represent 1,500 when the galvanometer is brought to zero, then A B E has a resistance of 150 units; and if the line has a resistance of five units per mile, the fault B is thirty miles from A. When this test is being made, the other end C of the line should be insulated. It is easy to find whether the resistance B E is nil, by repeating the experiment at C. If in this second test we obtain a distance B C, which, added to A B gives the total length, A C, the part B E can have no resistance. If, on the other hand, the sum of the resistances be greater than that due to A C, the excess is caused by the resistance of the fault. As we measure in one case $A B + B E$, and in the other $B C + B E$, the sum of these exceeds the resistance of A C by double the resistance of the fault. Suppose the line is eighty miles long, the resistance A C will be 400

units. If the fault has no resistance at B, the measure from c to B will be 400—150 or 250 units.

But we must endeavour to eliminate the resistance of this fault. Now, the resistance of c to E=280 units ; therefore

$$A B = \frac{(400 + 150) - 280}{2} = 135$$

and

$$B C = \frac{(400 + 280 - 150)}{2} = 265$$

each of these quantities divided by five shows that the fault is twenty-seven miles from A, and fifty-three miles from B.

FIG. 188.

This method would be perfect if the resistance of the fault were really constant and did not vary during the testing ; but these faults vary much, and especially during the testing, in consequence of the polarizing effects of the current ; and from this it happens that, except in the case of great faults with a small resistance, the method is defective. There are, however, other more exact methods, and of these we may explain to our readers the following.

Defects of insulation in submarine lines are usually due to a perforation of the gutta-percha. The opening gradually enlarges from the effects of the current, although polarization

may conceal it for a time. Rapidly reversed currents from a battery of 100 or more cells tend to enlarge the opening and render its resistance insignificant. A copper current passing through the fault to the sea seems to stop the opening better than a zinc current, because it causes a deposit of copper chloride and oxygen, whilst a zinc current gives rise to a disengagement of hydrogen and a deposit of salt. The bubbles

FIG. 189.

of gas formed under great pressure burst after a time, and the disengagement of gas temporarily enlarges the fault. When this takes place under the influence of the negative current, only a small enlargement of the opening is produced; but by the positive current the copper conductor is gradually eaten into, and this frequently occasions a solution of its continuity. There is no sign of this destructive action, for so long as the smallest trace of metal remains the resistance of the line is not sensibly affected. The operators in this case prefer to use the

positive current, because the signals are better, the currents are more intense and less liable to change from the effects of the fault. This practice is, however, reprehensible, for a defective cable should be used with negative currents only. A defective line may be used for an indefinite time, so long as the conductor remains continuous.

Sometimes faults of this kind are caused by the presence of foreign bodies in the insulating material. If a fragment of zinc or a piece of wire should establish a communication between the conducting core and the external covering of the cable, a fault would be produced having a resistance almost nil, and the nature of the fault would readily be recognized by the absence of polarization.

A fault of the second kind (solution of continuity) may easily be combined with one of the first kind; for the line may not only be broken, but also be in more or less perfect contact with the earth at the place of rupture. In this case it is impossible to operate simultaneously at the two extremities. We can only measure the resistance of each section of the cable, and estimate, according to the polarization, what fraction of the total observed resistance must be attributed to the fault itself. In this case, we can with certainty determine the maximum distance within which the fault must be situated. With the minimum of polarization, the denuded copper wire of a ruptured cable usually gives a resistance equal to several miles of the conducting wire.

Faults of this kind also often present themselves as a solution of continuity of the conductor, while the insulation at the point of rupture continues good. In a submarine cable, the distances of such faults may be very accurately measured by finding the capacity of the portion of the cable between the coast and the rupture. The capacity per unit of length being known, the testing shows the distance with great precision. It is scarcely possible to apply this method to overhead lines, as in them the insulation is rarely sufficiently good to give exact results.

Faults of the third kind (contact of two adjoining conductors) are easily discovered if the contact is local and has but a small resistance. In this case, the resistance of the loop produced by the contact is measured, and half of this will plainly correspond with the distance of the fault.

CHAPTER VII.

VARIOUS APPLICATIONS OF TELEGRAPHY.

Uses of the Telegraph on Railways—At Fires—With Armies in the Field—
For Meteorological Purposes, and for Weather Prediction—For Fishing—
In the Service of Justice—Floating Stations.

THE telegraph, coming into use at the same time as railways, has contributed much to the success of these, for it is difficult to imagine how the iron roads could have been worked without the telegraph.

The apparatus for sending orders along the line is like that used for ordinary purposes. For a long time Bréguet's apparatus was used at the railway stations in France. But some time ago the companies introduced Morse's apparatus, and the clerks daily devoted a portion of their time to practising the new method, which has now superseded the dial apparatus.

We have not, however, now to speak of these telegraphs. The public safety requires something more than these communications, namely, the semaphore signals visible to all, which indicate to the engine drivers the condition of the line.

On double lines of railway, where the trains on each line go always in the same direction, they can come into collision only in consequence of the stoppage or slackening of speed of a train that precedes another. The guard then displays a red flag at the rear of the train, or in case of a stoppage he walks back and places the flag at a certain distance behind. When this signal would not be distinctly visible he places *fog-signals* on the rails, and these explode with a loud report when a wheel passes over them.

Guards, pointsmen, &c., are also instructed to stop, by these signals, a train following too closely upon another, so that the interval between may be great enough to remove the risk of accidents.

At stations, crossings, and other places where caution is required, as for instance, at the extremities of tunnels, &c., there are more complete signals for stopping trains. In France* these generally consist of a large disc (fig. 190) placed beside the line and made to turn by a lever.

Every train has to stop when the plane of the disc is turned across the line, for that is the signal that the line is blocked.

FIG. 190.

When, on the other hand, the plane of the disc is parallel to the rails, the train is free to pass on. These discs are large enough to be seen even in foggy weather by the engine-drivers as they pass, and usually they are visible at a great distance.

At night a lantern is suspended to the disc, and shows a red light to the approaching trains when the line is not clear.

These signals are placed at some distance from the stations

* It must be remembered that the railway signals, military telegraphs, &c. described in this chapter are those used in France, unless otherwise expressly stated.—TR.

or other points where the trains must stop, so that the engine-drivers may be able to stop the train if required, by slackening speed as they pass the signal. This distance varies from 500 to 800 yards, and the signal is worked at this distance by means of a wire passing over pulleys.

The signals are not always visible at the place from which they are worked ; it was formerly usual to place near the lever a small duplicate signal put in motion by the disc itself, so that the signalman might be certain that the latter was at the proper position.

This duplicate signal has long been advantageously superseded by an electric bell. The disc is fitted with a horizontal lever which it carries round as it turns. When the line is blocked, this lever is in contact with a piece of metal by which the circuit of a galvanic battery is closed, and a current causes a bell to ring continuously, either near the working lever or at the station. As the circuit is closed only at the time when the disc is perpendicular to the rails, the sound of the bell will indicate with certainty when the signal is against the approach of a train. If, on the other hand, the electric bell does not act when the lever is in the proper position, this will be an indication that the apparatus has in some way become deranged, and an *employé* will be sent to put it right.

At night also the tinkling of the electric bell will show plainly when the line is blocked by the signal, and it has been proposed to so arrange the electric circuit that it should be broken in the event of the lamp attached to the signal going out—an accident which, however, rarely happens.

These stopping signals are quite sufficient on railways with double lines, and they are independent of the telegraph, which plays quite another part.

On railways with only one line, the German system of electric-bell signals was several years ago adopted in France. These bells serve to indicate to the railway staff, both at the station and along the line between the stations :—First, the departure of each train ; second, when help is required ; third, the necessity of immediately stopping all the trains ; fourth, runaway waggons on the line.

On some lines each station is provided with two bell apparatus—one at each end of the station ; and an electric

current is made constantly to pass between each pair of consecutive stations, so that if the current be interrupted and re-established at any point, a hammer will strike one blow on the corresponding bell. The apparatus at the stations is composed of a loud bell, the hammer of which is connected to an electro-magnet by rods and levers properly arranged (fig. 191).

FIG. 191

These levers are moved by wheelwork, A, set in motion by a weight and regulated by the intermittent motion of an escapement controlled by the electro-magnet.

The apparatus placed along the line consist of large bells attached to the signal cabins (fig. 192), and acted on as in the former case. But in the apparatus along the line the wire wound round the electro-magnet is, of course, connected at each end with the line wire.

By varying the number of strokes on the bell and the length of the intervals of time between them, different signals

may be produced. For example, if we indicate by dots the strokes on the bells, and by lines the intervals of time between two closely consecutive blows, thus .. ——— .. ——— .. we have a representation of double strokes of the bell thrice repeated. A table of this kind showing the meaning of the different signals is attached to the apparatus.

If a single stroke of the bell be heard it is an indication of the rupture of the wire and the suspension of the electric communication between the two stations. This might be occasioned

FIG. 192.

by a landslip or other obstacle, and of course due precautions would be taken accordingly. The bell-signal apparatus is very simple, and it requires no other attention than the winding up of the weight from time to time. Special instructions are, moreover, given by those in charge of the telegraphs to all persons concerned in understanding the details of the bell apparatus, so that they may take the requisite steps to ensure its regular action.

Applications of telegraphy to giving alarm of fire.—As far back as 1851 the town of Stuttgard was provided with a complete network of telegraphs connecting the stations of the fire brigades, and acting as a constant check upon the daily and nightly effectiveness of its watchmen. A recent work by M. Von Fischer Truenfeld tells us that Germany is almost the only country in Europe where this important service has been established with completeness. We learn also that in America most of the great centres have systems of telegraphs appropriated to giving alarm of fires.

Thanks to the use of this plan the proportion of serious fires at Berlin scarcely reaches 3 per cent., and at Hamburg it is

only 1·77, at Amsterdam it is 2·79, and at Frankfort 5 ; while at London it reaches 10 per cent. in spite of the prompt and powerful means applied by the Metropolitan Fire Brigade.

The city of Hamburg has two head stations, at which are placed the central fire brigade and the central police force. These are connected by seven lines stretching out towards the suburbs, and each line is connected with a certain number of fire and police stations by automatic apparatus, by which the fire stations are immediately informed of the locality of the fire. And, besides this, telegraphic messages can be sent from one station to another, so that proper arrangements for help may be made.

A fire is first signalled to the central station, where the measures required are arranged for, and from which they are directed.

The telegraphic apparatus is very simple. The alarms or current interruptors are placed in boxes covered by a pane of glass, fixed at the corners of the principal street, and at the railway stations. By these alarms certain signals are repeatedly made at the central station on a Morse receiver, the signals having been arranged on a disc, that is set in motion by pulling the handle. This handle is reached by breaking the glass or opening the box when a fire occurs.

At Hamburg there are forty-seven stations with the Morse apparatus, and fifty automatic alarms. Every station, except the central one, has its Morse instrument out of the circuit, but in the circuit is a very loud electric bell. A signal sent from one of the Morse stations is registered at the central station on a Morse instrument provided with an automatic detent. The central station then transmits the alarm to all the fire stations in the district, or if necessary, by means of a special commutator, to all the stations of the seven districts.

The plan adopted at Amsterdam is that called the circular system. The city is divided into three great circles, each having its office in communication with the central station. There are fire-brigades and police-stations in every great circle; and these are so connected that the police-stations are in one half and the fire-brigades in the other half of the circles. By this arrangement the two sets of stations can be divided, and each can communicate with its own central office.

A certain number of secondary circuits, with their centre at the fire-stations, are arranged in each circle. In general these secondary circuits are provided with automatic alarms only ; but this rule is not absolute. There is also a suburban circle with overhead wires ; the other circuits being connected by underground wires. There are thus three principal circles, thirteen secondary circles, and one suburban circle, fifty Morse instruments, and one hundred and thirty-five automatic fire-alarms. All the lines work with a closed circuit. The Morse apparatus is mounted in the same way as at Hamburg, and the communications are made in the same manner. Loud bells fixed on the banks of the canals give the alarm to vessels. At the central station there is an electromagnet which gives the alarm to all the stations, and by means of combinations of bells the central station can call any station separately, or all together. The machinery of the bell-alarm is set in motion by a weight, the current having only to liberate a detent, precisely as in the system of railway calls we have described above.

The third system of fire telegraphs is that used at Frankfort-on-the-Maine. Like the first, it is radiating, but the sectional lines are provided with branches. There are eight principal circuits and thirty-six branch circuits. The former connect stations furnished with apparatus for transmitting messages ; the latter have only calls or alarms. In all there are twenty-five Morse stations, thirty-one instruments, and fifty automatic alarms.

No house is more than 600 yards from an alarm ; and at all the stations officials are on duty night and day. The whole of the principal lines which connect the Morse apparatus and the alarms with the central station present a length of 3,300 yards, and are laid underground with insulated iron-wire. Besides the underground lines there are 2,000 yards of overhead wires, connected only with bells fixed in the dwellings of the regular or volunteer captains of brigades, and in the police-offices. These lines work with a closed circuit, as at Hamburg and Amsterdam.

The fire telegraphs in America resemble those we have just described, except that in cities an automatic arrangement acts at a central station, and at the same time as the alarm is

given the whole district in which the fire has broken out also receives the signal instantly and immediately. In a few seconds afterwards, orders are received from the central station, and thus unity of action is secured.

The value of this system is proved by the fact of nearly one hundred cities in the United States and in Canada having adopted it, and maintained it continuously in action. According to Mr. Saxton, the superintendent of the fire telegraphs at St. Louis, this system saves the fire assurance companies 549,000 dollars a year.

M. Truenfeld states that towns unprovided with fire telegraphs are liable to a larger proportion of serious fires, on account of the greater delay in the arrival of the firemen on the scene. On the other hand, the more perfectly the system of fire telegraphs is developed, the smaller is the proportion of serious fires.

Application of telegraphy to military operations.—According to M. Floridor Dumas, the first time a field telegraph was used in the French army was about 1857, when the great Kabylie was taken. Marshal Randon then ordered M. Lair, the head of the civil telegraphic service in Algiers, to follow up the head-quarters of the army with a wire attached to the trees. These orders were carried out, and it was from Souk-el-Arba, that, on the 24th May, 1857, the Marshal informed Algiers of the conquest of the first branches of the Djurjura.

When the possibility of following the head-quarters of an army in the field by movable telegraphs was thus established, the plan first adopted was to place the apparatus in a light waggon, and to load a second waggon with the materials required in the formation of the line itself. Cables being often used, the same vehicle was sometimes made to carry the instruments and the reel from which the cable was unwound.

These "carriage-stations" made it possible to communicate between the ends of the line even during the march. The carriages were divided into two compartments, one of which serving as an office, contained the instruments, while the second held the reels of cable. The office had a table on which the instruments were placed, and a box containing the

batteries served as a seat. A bell and commutators were placed in front, and the connections were made by binding screws and gutta-percha covered wires. At night the work was carried on by the aid of a lantern. In the other compartment, the axles of the reels were supported by iron bearings, four on each side. Canvas bags containing the tools, and baskets of supports were also carried here. When laying the line, these bags were hung at the workmen's waists.

The earth-wire is screwed to one of the springs of the vehicle, which is in metallic communication with the brass nave of the wheel, whence a metallic rod proceeds to the iron rim surrounding the wheel. The earth connection is therefore never interrupted by the motion of the carriage. This connection is often found to be inadequate.

The line-wire is attached to the ironwork that supports the reels, and through it communicates with the cable or wire, even during the process of paying out. The earth connection is very uncertain when the vehicle is in motion, and it is sometimes requisite to improve it by wetting the wheels, or by thrusting into the ground a spike provided with a hollow through which water is poured out.

The head-quarters carriage being required to frequently move from place to place, has the same mobility as the "carriage-station," but, as it has to contain no paying-out apparatus, there are no reels of cable, and it is therefore more roomy. One side is occupied by a long table on which the instruments are arranged, and the batteries are placed under the seat in front of it.

Twelve miles is about the average rate of progress per day. But as the "carriage-stations" carry only four-fifths that length of cable, other carriages have been made to bear a supply of cable and the poles on which the overhead wires are supported in some places. These same carriages also contain the various kinds of insulators, stretchers, &c., and the several tools and implements required for the work. The lamps of the carriages are so arranged as to be available for night work.

In very rough country recourse is had to mules with pack-saddles, and in this case the moveable telegraph-office is formed of a small square tent for the operator, with a three-legged table to carry the instruments. These and the batteries are

carried in cases provided with drawers for holding the fastenings, &c. The cases can be opened and any articles required taken out without the case having to be removed from the mule. The cases, tent, table, and bags of implements are borne by one mule, while a second mule has a reel of wire or cable suspended on each side of the pack-saddle. The handle for winding is so arranged as to be easily worked, and it serves as a brake in paying out. But as this operation cannot easily be accomplished on the mule's back, a hand-cart is used to carry the reel during the unrolling of the line. This hand-cart is very useful in broken ground, and for making short cuts where the road is tortuous; or, again, for crossing a stream or laying a submerged cable, when it can be placed in the stern of a boat.

The staff for the work consists of a sergeant, two corporals, and twelve men. The vehicles containing the reels lead the way, the "carriage-station" follows. The sergeant goes before, marking out the route; and the men, divided into three parties, share the labour as follows:—The first party dig out holes for the poles, if the line is to be an overhead one; if it is to be a subterranean, they open out the trench in which the cable is to be laid. The second party is engaged with the paying-out of the cable or wire, forming the joints, &c., and generally with passing on the cable ready for laying. The third party fixes the wire to the poles and makes them secure, or lays the cable in the ground and fills up the trench. The poles are usually about 60 yards apart. The ground is examined and the route indicated by special officers, who are responsible for the whole of the telegraphic service.

In a level country $1\frac{1}{4}$ miles of wire can be put up in one hour, and 3 miles of cable can be laid in the same time. Fig. 193 shows the details of all the operations we have described.

The lines can be very readily and quickly taken up, five or six men being sufficient for the work.

When the line has been laid, small squads are stationed at intervals to protect it, and among these are workmen capable of repairing any accidental or wilful injury it may sustain. The military authorities punish very severely any intentional damage done to the line by unfriendly inhabitants of the

Fig. 193.—Laying a Field Telegraph Line.

country, and the soldiers stationed along it have to defend it against the enemy.

Only the commander-in-chief, the commander of divisions of the army, and the head staff officers have the right to send telegraphic messages. These have to be written, for no verbal order can be accepted, and the telegraphic operator may insist upon this formality, by which he avoids personal responsibility. It is not always an easy matter to forward a telegraphic message from the field of battle. It is generally brought by a staff officer, and the rule adopted in other circumstances (of confirming the telegrams by letters within twenty-four hours) is also followed in actual warfare.

The messages are, of course, centralized at the flying station which accompanies the commander-in-chief, and the importance of this station in the circumstances of warfare will be easily understood. The use of cypher prevents the matter of the messages from being improperly revealed, and there is a special official whose duty is to translate the cypher. It would, of course, otherwise be possible to "tap" the line and become acquainted with the messages. By merely holding in the hand or placing in the mouth a wire derived from the main one, sounds may be heard and the signals be read by an expert. A message in ordinary language may thus become known by the enemy through the agency of a telegraphic operator. During the Secession War in the United States messages were several times "tapped" in this way.

The staff of military telegraphists should comprise four operators for each section and twelve or fourteen for the central station. It has been calculated that for an army of 80,000 men, there would be needed 15 officers, 500 men, 280 horses, and 50 carriages, capable of carrying about 300 miles of line. This would constitute a telegraphic brigade.

Our readers will doubtless be interested in the remarks made by M. Chauvin in a paper read before the Society of Telegraphic Engineers of London, concerning the results of military telegraphy as used by the Prussian army in France, in 1870. He first reminds us that in the campaign against Austria in 1866 it was well-nigh demonstrated that modern warfare is impossible without the aid of the electric telegraph on the battle-field. In Prussia, before the war broke out, a

number of operators from the Civil Telegraphic Service were prepared for war service. Soon after the war was declared 300 telegraphists were ready to go with the advanced guard of the army, and communications with the rear guard were quickly established. This telegraph corps were supplied with Morse instruments, and the bell telegraph was never used. It was provided with light posts and copper wires, and used also insulated wires and cables laid along the ground, or suspended, as occasion required.

A less slight line was set up by a second corps on small posts; and this was to provide communications by which provisions and munitions could be sent for to Prussia. A third corps of telegraphists followed the rear guard in its advance into French territory, and transformed these temporary lines into permanent ones, of the same power and dimensions as those used by the government. The utility of the electric telegraph was specially demonstrated in the sieges of towns and fortresses. Without the electric telegraph it would have been impossible to maintain the sieges of Paris and of Metz.

A circle of 100 miles of telegraph lines surrounded Paris, and as, of course, this vast circuit could not have been everywhere filled with soldiers, two lines of overhead wires were erected beyond the range of the French guns. Each of these had four wires, and connected twenty-four different stations, between which thousands of messages were every day transmitted. The Emperor of Germany stated to Moltke his opinion that without the telegraph it would have been impossible to undertake the siege of Paris, or to maintain that of Metz so long a time. Another advantage of the telegraph relates to supply and maintenance of war material. All the provisions of the immense Prussian army were procured from Germany, for it would have been impossible to have found sufficient supplies in the districts occupied. When supplies were asked for by telegraph, the reply stated the time at which they might be expected to arrive. The return home of sick and wounded soldiers was also much facilitated by the telegraph.

It often happened that the railway lines were blocked by trains conveying troops, cannons, military stores or provisions. It was by means of the telegraph that the trains with the sick

and wounded were enabled to reach the nearest hospital, and the system was so arranged that officers and soldiers were rarely permitted to send private telegrams. At a later period, however, where the number of stations had increased, such messages were allowed. Whenever that was the case, a special wire was set apart for private messages at fixed prices.

The military protection of the lines was organized by patrols. It was, nevertheless, rare for a line to remain in good order more than twenty-four hours, and the work of repairing was incessant. The only method of preventing damage was to make the French authorities responsible by imposing heavy requisitions on the neighbouring towns. This plan worked better than any other. In forming their lines the Prussians also made use of the large stores of telegraphic materials which they found in France.

In Prussia the inferior officers are exercised in the use of the telegraph at Berlin, and are afterwards sent as assistants to the principal towns in the various military divisions.

In England the military telegraph is one of the functions of the Royal Engineers, who are aided by civil assistants.

In Italy the Engineer corps are employed in the telegraphic service, and soldiers manipulate the instruments.

In Russia, four special companies have recently been formed of non-military telegraphists.

In Austria, the lines are the property of the Governmental Telegraph Department, which employs military assistants.

Application of the Telegraph to forecasting the weather.—In Romme's Report to the Assembly in 1793 on Chappe's aërial telegraph, he did not forget to mention, among the advantages of the new invention, the possibility of warning being given of the approach of storms for the benefit of mariners and agriculturists.

In an interesting work on this question, M. Marie-Davy states that Lavoisier had begun, in France, the publication of a journal of predictions founded on data supplied from the provinces ; but as he was unable to obtain his information with sufficient promptness, the publication was necessarily discontinued.

In England and in America, meteorological telegraphy has been largely developed ; and in France, thanks to the labour

of M. Leverrier, the Observatory of Paris has supplied forecasts which are published periodically. M. St.-Claire Deville, believing that Algiers is the centre from which emerge all the storms that pass over the Mediterranean, has made great efforts to establish posts of observation in that colony, which are regularly at work and are of great utility.

To Admiral Fitzroy is due the idea of forecasting the weather, and announcing coming storms and tempests some time in advance. He proposed to the English government the establishment of twenty meteorological stations on the coasts of the United Kingdom, which were to furnish the data for his forecasts.

It was a difficult matter to overcome the incredulity with which this project was at first received ; but his first predictions were so exactly verified, that by aid of the maritime insurance companies, all the English ports were soon provided with a meteorological station.

Admiral Fitzroy's forecasts were based on an exact scientific system, and it would be unjust to confound them with those of the modern prophets whose predictions appear monthly in certain minor French periodicals. Admiral Fitzroy explains his theory in a paper he has laid before the learned societies. He says that, as ordinary meteorological instruments commonly indicate important changes several days in advance, we may foretell the weather and the direction of the wind we expect the next day at a given place, from the morning observations, compared with those of the preceding days. We take the mean of these local indications to form that of the districts, and we then calculate what the result should be. On a map we place moveable arrows to show the direction of the winds, and the possibility of cyclones, and we observe their course and the movement of the wind about their centres, according as they meet, combine, or recede.

When the condition of the weather has been decided for all parts of England, notice of expected gales is sent to the threatened ports, at which alarm signals are immediately hoisted up, indicating the direction and force of the gale expected.

The French Meteorological Department also gives warning

of gales and of rainy or unsettled weather. As in England, the coasts are divided into regions, radiating towards mid-France and to the heights of the Alps and the Pyrenees. General Nansouty's celebrated Observatory on the Pic du Midi is certainly rendering important services to meteorology and weather forecasting, as well as to forewarning of floods.

The vast extent of America supplies the most varied observations; and there, in the Gulf of Mexico, originate those great cyclones that reach our shores. The meteorological observations made in those regions allow us to calculate, with almost mathematical precision, the date by which these cyclones will have crossed the Atlantic, their appearance often agreeing with the day foretold by the American observers.

As cyclones have a centre of depression which travels along, it is possible to follow the direction of the course; and it is precisely this which must be observed if we are to have any data for the prediction of the weather. By observing the first signs of the arrival of one of these cyclones or whirling movements, and by determining its extent and intensity, the distance at which it will pass into the region considered, the course it follows, and its speed of transmission, the time at which it will arrive at such or such a place may be stated. These predictions no doubt sometimes fail to be verified; for it is impossible to foresee the many causes of perturbation to which the cyclone may be subject in crossing the Atlantic. It is but seldom, however, that the warning of the approach of a great cyclone giving rise to violent gales is not justified by the event.

Meteorology is capable also of rendering great services to agriculture. "With standing crops," says M. Marie-Davy, "the husbandman has usually to take the weather as it comes; but at the time of tilling and sowing, and especially when the fruits of the earth are ready for gathering, it must be of undoubted utility for him to have warning of changes of weather, of approaching fine days and wet days, and, above all, of storms coming on. But, for these warnings to be effectual, they must reach even the hamlets. They should be clear and simple, not telling the farmers what they should do, but helping their own

experience of weather signs, and giving more reliability to their judgment by enlarging its bases; and the warnings should, moreover, be sufficiently in advance for those interested either to take precautions, or to select the most favourable period for undertaking operations that occupy some considerable time."

Other Applications of the Telegraph.—It would be vain to attempt to enumerate the resources which the use of the telegraph affords in numberless cases. We may, however, mention the value of the telegraph in cases of sudden and unusual floods in rivers. Great disasters may be prevented if the places down the stream receive timely warning. This service is now well organized in France. A hydromatic commission forms part of this service for all the great rivers of France. The overflow of the Seine in 1876 proved the value of this organization, by the services rendered by the commissioners under M. Belgrand. The Observatory on the Pic du Midi foretold, several days beforehand, the overflow of the Garonne in 1875.

The localities of the great herring and cod fisheries are well known; but when the fish come to deposit their spawn, great shoals disappear into the bays, and then the fish again take to the open sea. In Norway, herring fishing is perfectly organized by giving signals of the approach of the shoals. The neighbouring fishing-stations are connected by submarine cables, and intimations of the appearance of the shoals of herring in any particular *fjord* are sent to the fishing villages.

The police daily make use of the telegraph for tracing and arresting criminals. Count du Moncel states that lately it has been suggested that the autographic telegraph should be employed in reproducing portraits of such persons at a distance. Experiments were made with this object by M. D'Arlincourt in 1876 and 1877 at the chief police-office at Paris. It appears that the results were considered very satisfactory, and it is strange that this interesting application of telegraphy has not come into use; for a very ingenious class of telegraphic apparatus has already been devised, which would further the ends of justice.

We have only now to mention one more application of telegraphy, which was in use in England for a short time. We refer to the telegraphic ship, the *Brisk*, that was anchored in the Channel, and connected by a cable to the mainland. The object of this floating telegraph-station was the following:—

When the gale is strong in the Channel, a great number of vessels are detained at its mouth, and obliged to keep to the open sea. Their captains could then telegraph their position to the ship's agents, and homeward-bound ships could telegraph their approach to the Thames. This project was unsuccessful; the telegraph ship was badly anchored, and repeatedly broke her cable. Under such circumstances there was much risk for the operators; but these matters of detail might have been rectified. Mr. F. C. Webb, in fact, undertook to secure the ship by special appliances. These were not adopted, and in the end the company formed to work this scheme was wound up. The plan, nevertheless, appears practicable.

Stationary floats attached to a sunken cable could, it was then suggested, be laid down, and ships desiring to communicate with the shore might fish them up. A disabled ship might thus give its position in order that aid might be sent. It would not, of course, be necessary to lay such cables in deep waters. But lighter cables might be attached to one sunk at any depth from 3 to 400 fathoms, and might radiate towards the open sea. If buoys provided with bells were attached to the end of these light cables, ships desiring to communicate with the shore could easily find them, haul the cable on board, and connect it with their telegraphic instruments. Outward-bound ships might also thus receive their last instructions from the freighters. The advantages of such stations are sufficiently obvious, and their realisation appears practicable, while they would certainly be the means of preventing many a disaster. Such a loss, for example, as that of the *Atlanta*, when so much of youthful hope and promise perished, would have been avoided if the ship had had the means of communicating with the shore.

In concluding this work, we thank the indulgent reader who has followed our story to this point, and who, we are convinced, must participate in our admiration of these marvellous

appliances for communicating thought. Every month, nay, every day, brings to light some new fact, enriches the world of science with some unexpected discovery. When we behold the rapidity with which the domains of science are extending, we regret that our own life is so far spent, and we feel a kind of envy for that younger generation who are destined to witness a still greater extension of the resources of humanity.

THE END.

SMITHSONIAN LIBRARIES

3 9088 01983 0520