American Railway Signaling Principles and Practices

CHAPTER XXII

Manual and Controlled Manual Block Systems and Fundamental Theory of Direct Current

Published by the Signal Section, A. A. R.
30 Vesey Street, New York, N. Y.

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MANUAL AND CONTROLLED MANUAL BLOCK SYSTEMS

The Standard Code of the American Railway Association defines the following:

Block System.

A series of consecutive blocks.

Manual Block System.

A series of consecutive blocks, governed by block signals operated manually, upon information by telegraph, telephone or other means of communication.

Controlled Manual Block System.

A series of consecutive blocks governed by block signals, controlled by continuous track circuits, operated manually upon information by telegraph, telephone or other means of communication, and so constructed as to require the cooperation of the signalmen at both ends of the block to display a Clear or a Permissive Block Signal.

Block Station.

A place from which block signals are operated.

Block.

A length of track of defined limits, the use of which by trains is governed by block signals.

Fixed Signal.

A signal of fixed location indicating a condition affecting the movement of a train.

Block Signal.

A fixed signal at the entrance of a block to govern trains entering and using that block.

General.

In this chapter no attempt will be made to indicate in chronological order the sequence of events leading to the adoption of operating trains under block systems as this is fully covered in Chapter I—Development of Railway Signaling. Suffice to say that the block system is a means of maintaining a fixed minimum interval of space between two trains traveling in the same direction on the same track and to prevent two trains traveling in opposite directions from meeting on the same track. Prior to the adoption of the block system a predetermined interval of time was the means used to avoid collisions. The time interval is still in use on roads or parts of roads where trains usually follow one another only at long intervals.

There are three general types of block systems used on American railroads, they are designated as manual, controlled manual, and automatic; definitions for the first two are herein stated, the Automatic Block System is described in Chapter XV.

Rules.

In order that the reader may have a better conception of operating trains under a block system the Rules and Forms for Manual and Controlled Manual Block Systems, as contained in the Standard Code, are quoted:

"Note.—Rules and forms with the prefix 'M' are for Manual Block; those with the prefix 'C' are for Controlled Manual Block. Rules without a prefix are for both Manual and Controlled Manual Block Systems.

"The prefixes 'M' and 'C' to be printed in italics.

"305. Block signals govern the use of the blocks, but, unless otherwise provided, do not supersede the superiority of trains; nor dispense with the use or the observance of other signals whenever and wherever they may be required.

"C-305. Controlled manual block signals govern the use of the blocks, and, unless otherwise provided, their indications supersede time-table superiority and take the place of train orders; they do not dispense with the use or the observance of other signals whenever and wherever they may be required.

"306. When a block station is open at an irregular hour, trains must be notified by train order or by special instructions, and special precautions must be taken to call the attention of trains approaching such block station to the indications of the block signals.

"SIGNALMEN

"311. Signals must be kept in the position displaying the most restrictive indication, except when displayed for an immediate movement.

"312. Appliances must be operated carefully and only by those charged with that duty. If any irregularity affecting their operation is detected the signals must be displayed to give their most restrictive indication until repairs are made.

"313. Signalmen must observe, as far as practicable, whether the indications of the signals correspond with the positions of the levers.

"314. Signalmen must not make nor permit any unauthorized repairs, alterations or additions to the apparatus.

"315. A block record must be kept at each block station.

Note to Rule 315.—The different items to be entered on the block record have not been prescribed in this rule, but it has been left to each railroad to complete the rule by adding such items as may be necessary to meet the conditions governing its traffic.

"316. COMMUNICATING CODE.

1.—Display Stop-signal.
13.—I understand.
17.—Display Stop-signal. Train following.
2.—Block clear.
3.—Block wanted for train other than passenger.
36.—Block wanted for passenger train.
4.—Train other than passenger has entered block.
46.—Passenger train has entered block.
5.—Block is not clear of train other than passenger.
56.—Block is not clear of passenger train.
7.—Train following.
8.—Opening block station. Answer by 2, 5 or 56.
9.—Closing block station, followed by 2.

"If the block is clear, to be answered by 13, followed by 2.

"If the block is not clear, to be answered by 5 or 56.

"When two or more tracks are used in the same direction, signalmen in using the communicating code must also specify the track.

"317-A. To admit a train to a block, the signalman must examine the block record, and, if the block is clear, give '1 for ....,' to the next block station in advance. The signalman receiving this signal, if the block is clear, must display the Stop-signal to opposing trains, and reply '2 for ....,' and when necessary unlock the next block in the rear. If the block is not clear, he must reply '5 of ....,' or '56 of ....' The signalman at the entrance of the block must then display the proper signal indication.

"A train must not be admitted to a block unless it is clear, except as provided in Rules *M*-333, *C*-333 or by train order.

"317-B. To admit a train to a block, the signalman must examine the block record, and, if the block is clear, give '3 or 36 for ....,' to the next block station in advance. The signalman receiving this signal, if the block is clear, must display the Stop-signal to opposing trains and reply '2 for ....,' and when necessary unlock the next block in the rear. If the block is not clear, he must reply '5 of ....,' or '56 of ....' The signalman at the entrance of the block must then display the proper signal indication.

"A train must not be admitted to a block which is occupied by an opposing train or by a passenger train, except as provided in Rules *M*-333, *C*-333 or by train order.

"To permit a train to follow a train other than a passenger train into a block, the signalman must give '17 for ....,' to the next block station in advance. The signalman receiving this signal, if there is no passenger train in the block, must reply '5 of ...., 13 for ....' The approaching train will then be admitted to the block ....*

Note to Rule 316.—Additions to the communicating code may be made if desired. When telephone is used the code will be used without the numerals.

Note to Rule 317-A.—317-A is for absolute block for following and opposing movements on the same track.

Notes to Rule 317-B.—

Rule 317-B is for absolute block for opposing movements, and permissive block for following movements on the same track.

* Under Permissive-signal or with Clearance Form B.

"318-A. To admit a train to a block, the signalman must examine the block record, and, if the block is clear, give '3 for ....,' or '36 for ....,' to the next block station in advance. The signalman receiving this signal, if the block is clear, must reply '2 for ....,' and when necessary unlock the next block in the rear. If the block is not clear, he must reply '5 of ....,' or '56 of ....' The signalman at the entrance of the block must then display the proper signal indication.

"A train must not be admitted to a block unless it is clear, except as provided in Rules *M*-333, *C*-333 or by train order.

"318-B. To admit a train to a block, the signalman must examine the block record, and, if the block is not occupied by a passenger train, give '3 for ....,' or '36 for ....,' to the next block station in advance. The signalman receiving this signal, if the block is clear, must reply '2 for ....,' and when necessary unlock the next block in the rear. If the block is not clear, he must reply '5 of ....,' or '56 of ....' The signalman at the entrance of the block must then display the proper signal indication.

"A train must not be admitted to a block which is occupied by a passenger train, except as provided in Rules *M*-333, *C*-333 or by train order.

"A train may be permitted to follow a train other than a passenger train into a block ....*

"319. When a train enters a block, the signalman must give '4 ....,' or '46 ....,' and the time, to the next block station in advance, and when the train has passed the Home or Block Signal and the signalman has seen the markers he must display the Stop-signal, and when the rear of the train has passed .... feet beyond the Home or Block Signal, he must give the record of the train to the next block station in the rear.

"This information must be entered on the block records.

"320. Unless otherwise provided, signalmen must not ask for the block until they have received a report of the train from the next block station in the rear, nor unlock the next block in the rear until the block is asked for by that block station.

"321. Signalmen must, as far as practicable, observe all passing trains and note whether they are complete and in order, and the markers properly displayed.

"322. Should a train pass a block station with any indication of conditions endangering the train, or a train on another track, the signalman must immediately notify the signalman at the next block station in advance, and

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Note to Rule 318-A.—Rule 318-A is for absolute block for following movements only.

Notes to Rule 318-B.—

Rule 318-B is for permissive block for following movements only.

* Under Permissive-signal or with Clearance Form B.

Note to Rules 317-A, 317-B, 318-A and 318-B.—Where it is desired that train dispatchers shall control the display of block signals, railroads may modify Rules 317-A, 317-B, 318-A and 318-B so as to provide for such practice.

Note to Rules 317-A, 317-B, 318-A, 318-B, and 319.—The blanks in Rules 317-A, 317-B, 318-A, 318-B and 319 are to be filled by the number or designation of the train, except as otherwise noted.

each must display Stop-signals to all trains that may be affected, and must not permit any train to proceed until it is known that its track is not obstructed.

"323. Should a train without markers pass a block station, the signalman must notify the signalman at the next block station in each direction, and must not report that train clear of the block nor unlock the next block in the rear until he has ascertained that the train is complete.

"324. Should a train pass a block station in two or more parts, the signalman must stop all trains moving in the same direction and notify the signalman at the next block station in advance. A signalman having received this notice must stop all trains moving in the opposite direction. The Stop-signal must not be displayed to the engineman of the parted train if the train can be admitted to the block in advance under Block Signal Rules; but the Train-parted signal must be given. Should a train in either direction be stopped, it may be permitted to proceed when it is known that its track is not obstructed.

"325. A signalman informed of any obstruction in a block must immediately notify the signalman at the other end of the block and each must display Stop-signals to all trains that may be affected and must not permit any train to proceed until it is known that its track is not obstructed.

"326. When a train takes a siding or otherwise clears the main track the signalman must know that it is clear of the block before giving 2 or displaying a Clear-signal for that block.

"The signalman must obtain control of the block before permitting a train to re-enter the block.

"327. To permit a train to cross over or return, unless otherwise provided, the signalman must examine the block record, and if all the blocks affected are clear of approaching trains he must arrange with the signalman at the next block station in each direction to protect the movement, and when the proper signals have been displayed, permission may be given. Until the block is clear no train must be admitted in the direction of the cross-over switches except under Permissive-signal or with Clearance Form B.

"All cross-over movements must be entered on the block records.

"328. When coupled trains are separated, as prescribed by Rule 364, the signalman must regard each portion as an independent train.

"329. When necessary to stop a train for which a Clear or Permissive signal has been displayed and accepted, the signalman must give hand signals in addition to displaying the Stop-signal.

"330. A signalman having train orders for a train must display the block signal at Stop. He may permit trains so stopped to proceed under Block Signal Rules after complying with Rules for Movement by Train Orders.

"*M*-331. When from the failure of block signal apparatus, the block signal cannot be changed from its most restrictive indication, a signalman having information from signalman at the next block station in advance that the block is clear, may admit a train to the block by the use of Clearance Form A.

"If the block is occupied by a train, other than an opposing train or a passenger train, the signalman may admit a following train by use of Clearance Form B.

"*C*-331. When from the failure of the block signal apparatus, the block signal cannot be changed from its most restrictive indication, or when a signalman is unable to communicate with the next block station in advance, he may admit a train to the block by the use of Clearance Form B.

"332. Operating levers must be blocked or marked and should not be used when a track, switch or signal is undergoing repairs, or when a track is obstructed.

"*M*-333. When, from any cause, a signalman is unable to communicate with the next block station in advance, he must stop all trains approaching in that direction. Should no cause for detaining a train be known, it may then be permitted to proceed with Clearance Form B, provided .... minutes have elapsed since the passage of the last preceding train.

"*C*-333. When a signalman is unable to communicate with the next block station in advance, or if from the failure of the block signal apparatus the block signal cannot be changed from the normal indication, he must set his signal and other apparatus to display their most restrictive indication, stop all trains approaching in that direction and be governed by instructions from the .... If unable to communicate with the ...., he will, after any train for which 2 or 13 had been given to the next block station in advance has cleared the block, permit trains to proceed on their time-table or train order authority, with Clearance Form B and under Stop-signal.

"334. Hand signals must not be used when the proper indication can be displayed by the block signals, except as prescribed by Rule 329 or 343. When hand signals are necessary they must be given from such a place and in such a way that there can be no misunderstanding on the part of enginemen or trainmen as to the signals, or as to the train or engine for which they are intended.

"335. Block signals for a track apply only to trains moving with the current of traffic on that track. Signalmen will use .... for blocking trains moving against the current of traffic.

"336. Signalmen will be held responsible for the care of the block station, lamps and supplies; and, unless otherwise provided, of the signal apparatus.

"337. Lights in block stations must be so placed that they cannot be seen from approaching trains.

"338. If a train overruns a Stop-signal, the fact must be reported to ....

"339. If a Stop-signal is disregarded, the fact must be reported to the next block station in advance and then to ....

"340. To open a block station the signalman must give 8 to the next block station in each direction and record the trains that are in the extended block.

Note to Rule *C*-331.—Rule *C*-331 is for operation on two or more main tracks for following movements only.

Note to Rule *C*-333.—Rule *C*-333 is for operation on single track.

Note to Rule 334.—Hand signaling includes the use of flag, lamp, torpedo and fusee signals.

Note to Rule 335.—Each railroad may fill in the blank in Rule 335 with the kind of signals that are to be displayed or with the Form to be used by the signalmen.

He must then display the most restrictive signal indication and notify the next block station in each direction that the block station is open.

"When trains, which were in the extended block when the block station was opened and which had passed his block station before it was opened, clear the block in advance he must repeat the record to the block station in the rear.

"341. A block station must not be closed except upon authority of ....

"342. Unless otherwise provided, a block station must not be closed until the block in each direction is clear of all trains.

"To close a block station, the signalman must give 9 followed by 2 to the next block station in each direction and when he receives 13 followed by 2 enter it on his block record, with the time it is received from each block station.

"The block signals must then be secured in the .... position, all lights extinguished, and the block wires and, when necessary, circuits arranged to work through the closed block station.

"343. When a block station is open at an irregular hour, signalmen must use hand signals, in addition to block signals, to give the required indications until all trains have passed which have not been notified by train order or by special instructions that the block station is open. Signalmen must take special precautions to call the attention of trains approaching the block station to the indications of the block signals.

"344. Signalmen must not permit unauthorized persons to enter the block station.

"ENGINEMEN AND TRAINMEN

"361. Block signals for a track apply only to trains moving with the current of traffic on that track.

"............... will be used for blocking trains moving against the current of traffic.

"*M*-362. Trains must not pass a Stop-signal without receiving Clearance Form A, Clearance Form B, or a train order authorizing them to do so.

"*C*-362. Trains must not pass a Stop-signal without receiving Clearance Form B, or a train order authorizing them to do so.

"On single track, trains receiving Clearance Form B may proceed on their time-table or train order authority expecting to find a train in the block, a broken rail or a switch not properly lined.

"363. Trains must not proceed on hand signals as against block signals.

"364. Unless otherwise directed, when two or more trains have been coupled and so move past any block station, they must be separated only at a block station and the signalman notified.

"365. When a train takes a siding or otherwise clears the main track it must not again enter the block or foul the main track without the permission of the signalman.

"A train having passed beyond the limits of a block must not back into that block without permission from the signalman.

Note to Rule 361.—Each railroad may fill in the blank in Rule 361 with the kind of signals that are to be displayed or with the Form to be used by the signalmen.

"366. Unless otherwise provided, when it is necessary for a train to cross over, the signalman must be notified and permission obtained before crossing over or returning.

"367. The engineman of a train which has parted must sound the whistle signal for Train-parted when approaching a block station.

"368. An engineman receiving a Train-parted signal from a signalman must answer by the whistle signal for Train-parted.

"369. When a parted train is recoupled the signalman must be notified.

"370. When there is an obstruction between block stations, notice must be given to the nearest signalman.

"371. When a train is stopped by a home or block signal the conductor and engineman must immediately ascertain the cause.

"372. Conductors must report to .... any unusual detention at block stations.

"373. A block station must not be considered as closed, except as provided for by time-table or special instructions."

Manual Block

As the name implies, manual block is a method of spacing trains in which the signals or other means of displaying indications are operated manually, without electrical or mechanical check, subject only to rules. Manual block is flexible since the facilities provided can be increased or decreased as traffic warrants by shortening or lengthening the blocks. The protection afforded is against head-on and rear-end collisions.

Double track.

Figure 1 illustrates a section of double track with block stations spaced approximately 5 miles apart. There is a signalman or block operator on duty at each block station shown, with necessary means of communication between block stations, also between these stations and the train dispatcher located at some distant point. The means of communication are generally the telegraph, telephone, or both.

At each block station there are two manually-operated block signals with approach signals to govern the approach of trains to the block signals.

When a train passes block station A the signalman reports this fact to block station B. The signalman at B, on receiving this information, makes entry on his block sheet and then, according to Rule 318-B, communicates with the signalman at C regarding condition of block and displays the proper signal. When train enters block at block station B the signalman at B communicates with signalman at block station C giving him the time train passed B. When train has passed the block signal at B and the signalman has seen the markers he must display the stop signal. When rear of the train has passed the block signal a specified distance he must give record of the train to block station A. This information must also be entered on the block sheet. The block sheet at block station B would then show time that train passed block stations A, B and C. Should it be necessary for the train to be held at block station B for any

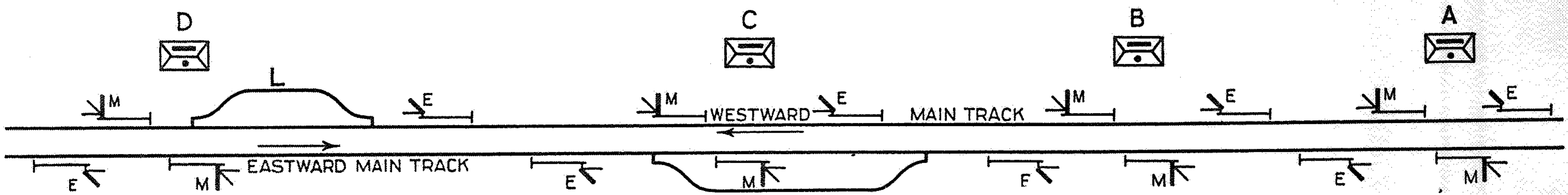

Fig. 1.
Arrangement of Manual Block Station, Double Track.

reason this fact would also be recorded by an arriving and departing time for that train being shown with a short explanation as to the cause. If the train is not held at the block station only one time is shown, which is entered in the D or "departed" column. Part of a typical block sheet record for block station B is shown in Fig. 2.

Provision is made for fast moving trains to pass slower moving trains by the use of sidings as shown in Fig. 1. A freight train traveling from A toward D and has passed C about the time a passenger train passes A: the freight train will not have time to get to D before the passenger train reaches C, therefore the freight train enters siding L and after it is clear of main track, switch closed and locked, the conductor reports this fact to the operator at C who then displays a clear signal for the passenger train which passes the freight train. After the passenger train passes D, the operator gives permission to the freight train to move from the siding and proceed toward D. By referring to Rule 318-B it will be seen that a train must not be admitted to a block which is occupied by a passenger train. If one freight train is passing another freight train, the slower train can follow from the siding as soon as the first train has passed and permission is received from the operator.

Various arrangements are in effect relative to method to be followed should means of communication fail between an outlying point and the signalman. One method prescribes that if, from any cause, conductor or engineman is unable to communicate with the signalman either by the usual means of communication or the use of commercial lines and should no cause for detaining the train be known it may proceed through block on its rights or time-table authority, preceded by a flagman to the next point of communication and report to the Superintendent.

Single track.

Figure 3 illustrates a section of railroad where trains are operated in both directions on the same track. It is usually necessary to have more sidings in single-track territory than in double-track. The frequency of sidings is determined by the density of traffic. Assume two trains of the same class traveling toward each other from block stations A and D: the train traveling from A to D is superior by direction to the train traveling from D to A, so that it will be necessary for the latter train to clear on a siding before the superior train is due to leave the block station at that siding.

The signalman at block station A has obtained the block from block station B in accordance with Rule 317-B and a clear block signal is displayed for movement from A to B. Shortly after the superior train passes block station A, the inferior train in opposite direction approaches block station D. The signalman at D obtains the block from the signalman at C so that the inferior train passes block station D with a clear block signal. As the superior train approaches block station B this signalman has obtained the block from block station C and this train is given a clear block signal at B. The inferior train approaches block station C, but the signalman must keep both his block signals in the stop position as a train is approaching him from each direction. The inferior train approaching from D stops before reaching the switch at entrance to siding. A

THE A AND B RAILROAD XYZ DIVISION

STATION RECORD OF TRAIN MOVEMENTS AT "B" Block STATION Dec. 3 19 35

Went on Duty	Went off Duty	Signalman or Operator	Leverman	Time	Weather	Temp.
12.01 AM	7.00 AM	P.S. Duer		5.00AM	Light Fog	25
7.00 AM	3.00 PM	E.H. Smith		11.00AM	Cloudy	33
3.00PM	11.00 PM	M.M. Moore		5.00PM	Cloudy	38
11.00PM	11.59 PM	D.W. Lewis		11.00PM	Rain	42

INSTRUCTIONS

1. This record shall be made at each station, tower office, or place from which the time of arrival, departure, or passing of trains is reported by telegraph or telephone.
2. Each operator, signalman, and leverman shall enter the time he goes on and off duty in the space provided for that purpose.

TRANSFER RECORD

	AT 7.00 AM	AT 3.00 PM	AT 11.00 PM
31 ORDERS UNDELIVERED FOR TRAIN NOS.	None	None	None
19 " " " " "	"	"	"
MESSAGES " " " "	"	"	"
OVERDUE TRAINS "	"	"	"
NOTED AND UNDERSTOOD—(SIGNED)	E.H.S.	M.M.M.	D.W.L.

East WARD

TRAIN	ENG.	"2" OR "13" TIME GIVEN	A TIME DEPARTED	A TRK.	"2" OR "13" TIME RECEIVED	B TIME ARRIVED	B TRK.	B TIME DEPARTED	B TRK.	BLOCK CLEARED AT	REMARKS
913	8281	129	145		146			214		250	At C - Clear
PB1	3715	502	520		601			620		645	At C - Clear
BF1	4371	729	734		755			802		830	At C - Clear
903	3862	805	810		832	830		832		851	At C-Stop-Clear

West WARD

TRAIN	ENG.	"2" OR "13" TIME GIVEN	C TIME DEPARTED	C TRK.	"2" OR "13" TIME RECEIVED	B TIME ARRIVED	B TRK.	B TIME DEPARTED	B TRK.	BLOCK CLEARED AT	REMARKS
912	3672	345	349		355			430		459	At A - Clear
PB2	1570	438	440		502	530		535		602	At A - Clear
TCX	4926	605	610		-	625		-		-	Clear at B
502	4472	630	640		645			700		720	At A - Clear

Fig. 2.
Typical Block Sheet.

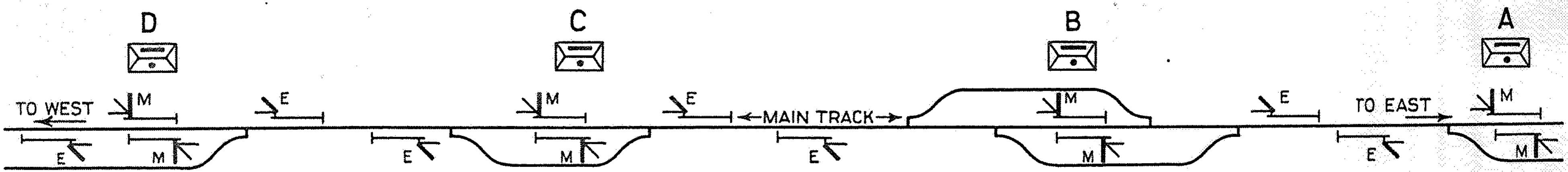

Fig. 3.
Arrangement of Manual Block Station, Single Track.

member of the train crew sets the switch for movement to the siding and train then enters siding, and when the rear of the train is clear at the following point, the main track switch is restored to its normal position and the conductor reports his train clear of the main track, switch closed and locked. Signalmen at block stations D and C make proper record on their block sheets and signalman at C then requests block from signalman at D for superior train approaching from block station B. After this permission is obtained signalman at C clears the block signal allowing superior train to proceed toward block station D without a stop at C. On arriving at the other end of siding, the conductor of the inferior train calls block station C for permission to proceed on the main track to block station B. As the superior train has passed block station C and the signalman has so recorded it on his block sheet and reported it to signalman at B, he requests the block from signalman at B to permit the inferior train to proceed toward B. After receiving this permission he authorizes the train on siding to proceed to block station B and also advises him as to the condition of the block, which in this case is clear. Signalman at B then obtains block from signalman at A, so that he can display proper signal for the inferior train as it approaches his block station.

In the case of passenger trains only one train is permitted in either direction between block stations; no other train is permitted to occupy that block. A large number of railroads permit freight trains to follow each other in the same direction in the same block, this is termed permissive blocking. On some railroads only one train is permitted in either direction in the same block at the same time and this is known as absolute blocking. By referring to the Rules quoted it will be seen which of these Rules prescribe the method in effect.

Various arrangements of sidings are in effect on different railroads. In some cases one end of the siding is at the block station, in other cases it may be midway between block stations, while in other cases there may be two or more sidings between block stations.

In some cases what are known as lap sidings are used, one of which is shown at block station B, Fig. 3. With this arrangement it can be seen that parallel movements can be made and that meets can be arranged without either train stopping. Where traffic warrants, the siding switches may be interlocked, or provided with a spring attachment.

Controlled Manual Block

Under this system the signals are operated manually, controlled by track circuits and other electrical and mechanical agencies subject to the rules already mentioned. In addition to the operators communicating with each other to obtain the use of the block, they must cooperate with each other so that one must operate a lever or device which releases a lever or device in the other block station permitting this operator to display a signal for desired movement of train and at the same time locking his own machine in such a way that he cannot display an opposing signal.

With Controlled Manual Block System Rules in effect, trains may run on signal indications which supersede time-table superiority and take the place of train orders. The circuits for a section of track between block stations A and B,

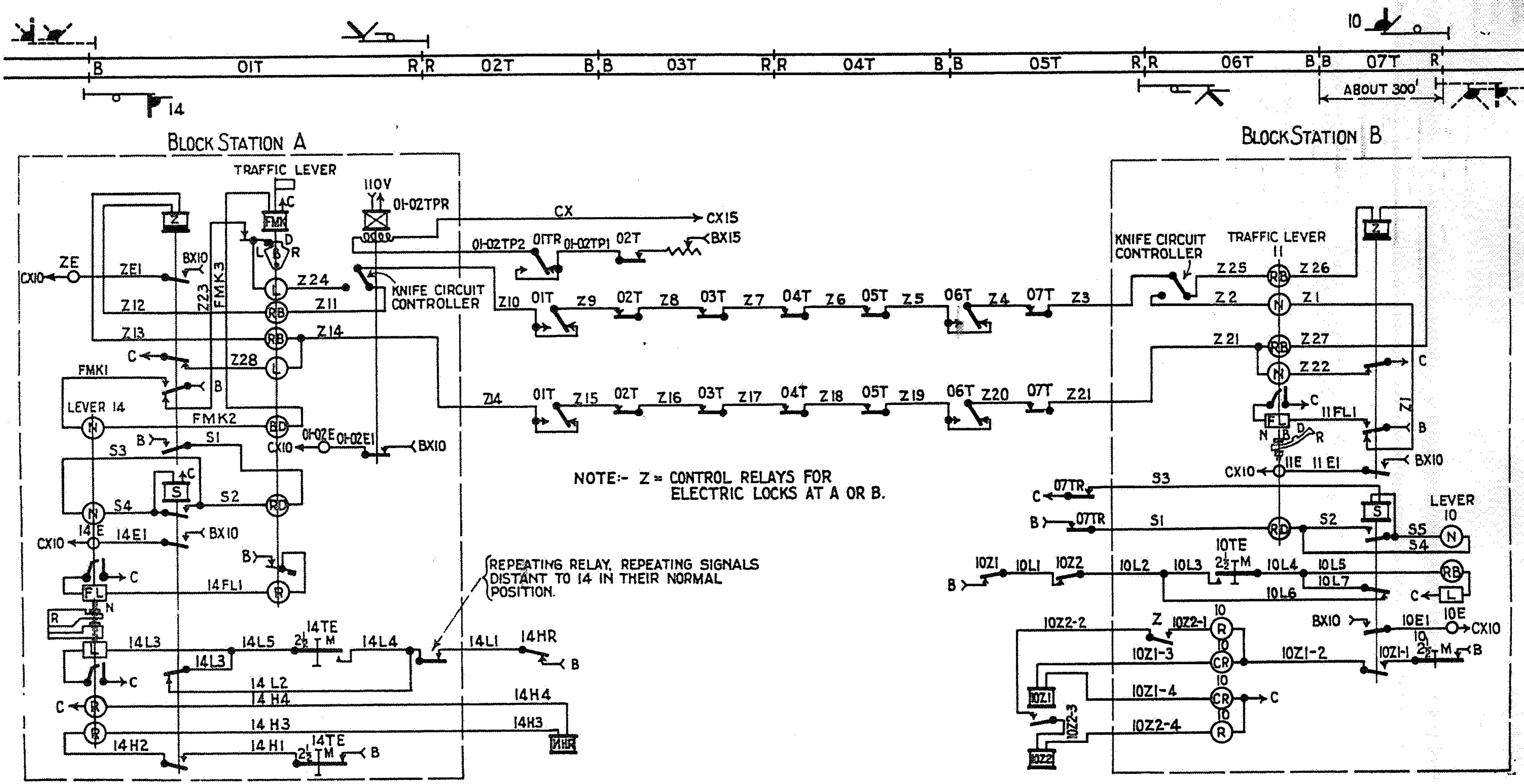

Fig. 4.
Circuits for a Controlled Manual Block, without Sidings.

which are also interlocking stations, are shown in Fig. 4. The circuits for only one track are shown, but if there are multiple tracks operated under Controlled Manual Block Rules the circuits for the other tracks would be practically the same as those shown for the one track.

At block station A signal 14 governs movements to block station B, while signal 10 at block station B governs movements to block station A. Before either signal can be cleared the signalman at each block station must manipulate the levers in a predetermined order. At each block station there is what is called a "traffic lever." With this lever in normal position movements can be made toward that particular block station, while with the traffic lever in reverse position movements can be made from that block station. The circuits as shown have the traffic lever at each block station in normal position. The machine at block station A, which also controls the interlocking, is a mechanical interlocking machine, while that at block station B is an electric interlocking

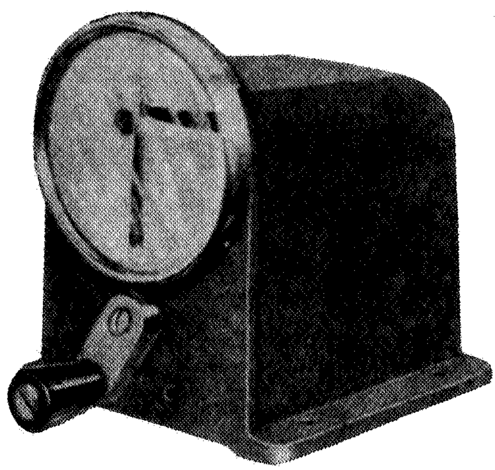

Fig. 5.
Electrically-Locked Circuit Controller and Indicator.

machine. The traffic lever FMK at block station A is not part of the interlocking machine, but is a separate unit known as an "electrically-locked semaphore indicator and circuit controller," shown in Fig. 5, the normal position of lever being the B or indicating position. The traffic lever at block station B is part of the interlocking machine and is No. 11, having two positions, normal and reverse.

At block station A there is electric locking between traffic lever FMK and signal lever 14, while at block station B there is mechanical locking between traffic lever 11 and signal lever 10.

Block stations A and B are located approximately 6 miles apart and in this particular layout there are no sidings between them. Due to grades and certain other local conditions it is desirable to operate under absolute block from A to B, but from B to A permissive blocking is allowed; therefore, signal 14 at A is only two-position, displaying "stop," and "clear," while signal 10 at B is three-position, displaying "stop," "permissive" and "clear."

Assume a train movement is to be made from A to B: signalman at A will communicate with signalman at B in accordance with Rule 317-B. If there is no reason why the movement cannot be made, signalman at A will see that lever FMK is in the B or indicating position and signalman at B will move his knife circuit controller to the opposite position from that shown, which will release lever FMK at A as follows: B at block station B, through back contact of relay Z, wire Z1 through contact of traffic lever 11 closed in normal position, wire Z2 through contact of knife circuit controller closed in reverse position, wire Z3 through contacts of all track relays between block stations B and A to insure that the block is unoccupied, wire Z10 through contact of knife circuit controller at block station A, closed in normal position, wire Z11 through contact of instrument FMK closed between the B and R positions, wire Z12 through coils of relay Z, wire Z13 through contact of instrument FMK closed between B and R positions, wire Z14 through another set of contacts on track relays between block stations A and B for protection from crosses and grounds, wire Z21 through contact of traffic lever 11 closed in normal position, wire Z22 through back contact of relay Z, to C. This circuit will energize relay Z at block station A which will light lamp ZE as follows: BX10 through front contact of relay Z, wire ZE1 to ZE, to CX10. With relay Z at A energized, it completes a circuit from B through front contact of relay Z, wire FMK1 through contact of signal lever 14 closed in normal position, wire FMK2 through contact of FMK closed between B and D positions, wire FMK3 through coils of FMK to C. This energizes the coils of the lock of instrument FMK, thereby releasing lever FMK so that it may be moved to the R position. As soon as this lever passes the D position, contact BD will be opened, de-energizing coils of FMK, closing the armature checking contacts, which will complete a circuit from B through armature contact of FMK closed when lock FMK is de-energized, through contact of lever FMK closed in the R position, wire 14FL1 to coils of electric lock FL on signal lever 14, through latch contact of same lever to C. This releases signal lever 14 from the normal position, permitting it to be moved to the reverse position which will cause signal 14 to display a clear signal by completing a circuit from B through normal contact of time release 14TE, wire 14H1 through front contact of relay S (stick relay controlled through relay Z to insure that track is unoccupied between A and B), wire 14H2 through contact of signal lever 14 closed in reverse position, wire 14H3 through coils of relay 14HR, wire 14H4 through contact of signal lever 14 closed in reverse position to C. Relay 14HR, now energized, causes signal 14 to display a proceed indication, the circuits not being shown. Under these conditions the signalman at B could not unlock traffic lever 11 and therefore could not move signal lever 10 to the right as the mechanical locking between levers 11 and 10 is such that lever 11 must be in reverse position before lever 10 can be moved to the R position. Before traffic can be set up from B to A, signal lever 14 at A must be in normal position, all track sections between A and B unoccupied and lever of instrument FMK in L position.

The circuit that allows the return of signal lever 14 to the normal position is from B through back contact of relay 14HR, wire 14L1 through front contact of relay repeating approach signals to signal 14, wire 14L2 through back contact of relay S, wire 14L3 through coils of lock L on lever 14, through latch contact of lever 14 to C. A release circuit is provided through time release 14TE should it be necessary to restore signal lever 14 to normal position before train, for which it had been reversed, passes signal 14. This release by-passes the back contact of relay S, wire 14L4 through back contact of time release 14TE and wire 14L5. The time for which time release 14TE is set depends on the distance between signal 14 and its approach signal, which in this case is set at 2 minutes and 30 seconds. With signal lever 14 in normal position, lever FMK is released by the circuit previously described so that FMK can be placed in the L position as follows: B through front contact of relay Z, wire FMK1 through contact of lever 14 closed in the normal position, wire FMK2 through contact of instrument FMK closed between the B and D positions, wire FMK3 to coils of instrument FMK to C. For a train movement from B to A, the signalman at A will then move lever FMK to the L position and his knife circuit controller to the reverse position and this will permit the signalman at B to reverse traffic lever 11. This circuit can be traced in much the same manner as described in releasing lever FMK at A. With lever of instrument FMK at A in the L position it will be seen that signal lever 14 is locked in the normal position N.

Since signal 10 at B can display the permissive indication for following trains there is a short track circuit of approximately 300 feet immediately in advance of the signal to insure that regardless of whether the signal is permissive or clear it will be returned to the stop position as soon as a train passes it and cannot again be displayed in either proceed positions unless the signalman restores the lever to the normal position and then moves it to the C (permissive) or the R (clear) position. These circuits are similar to those described in Chapter XX—Interlocking Circuits. The other circuits in this figure are about the same as those already described herein or as described in Chapter XX.

If sidings or tracks on which trains may clear the main track are located between block stations it is necessary to provide certain safeguards on the switches of these sidings or tracks to prevent their operation until released by the signalman at one of the adjacent block stations.

Figure 6 illustrates a track arrangement where there are two sidings between block stations A and B, siding C being controlled from A and siding D from B. In this particular installation the circuits as arranged allow a train to leave eastward siding at switch C, and to enter or leave the siding at switch D.

In this installation block stations A and B are both equipped with mechanically interlocked circuit controllers LFMK and FMK, as shown in Fig. 7. It will also be noted that instruments LFMK have their locking segments cut differently than that shown in Fig. 4 and the normal position of both levers is the B or indicating position.

Assume a movement is to be made from A to B. Signalman at A will communicate with signalman at B in accordance with Rule 317-B. The signalman at B will move lever of instrument LFMK to the L position and his knife circuit controller to the reverse position, which will complete circuit from B at station B through front contact of relay 08-09-010TPR, wire FMK1 through contact of signal lever 10 closed in normal position, wire FMK2 through arma-

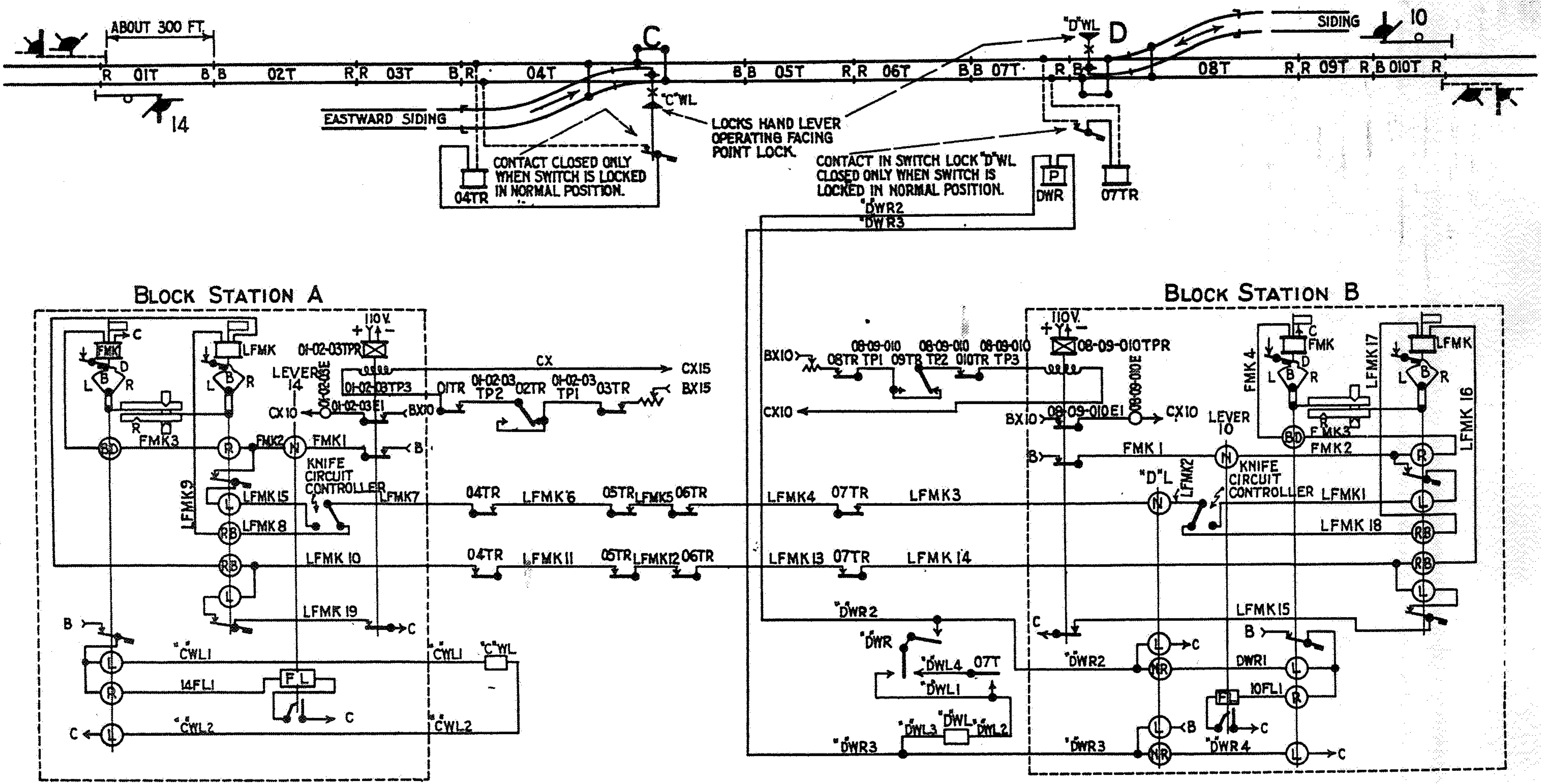

Fig 6
Circuits for a Controlled Manual Block, with Sidings.

ture contact of instrument LFMK, closed when the lock is de-energized, through lever contact of LFMK closed in the L position, wire LFMK1 through knife circuit controller closed in the reverse position, wire LFMK2 through contact of hand circuit controller DL closed in the normal position, wire LFMK3 through front contact of relay 07TR, wire LFMK4 through front contact of relay 06TR, wire LFMK5 through front contact of relay 05TR, wire LFMK6 through front contact of relay 04TR, wire LFMK7 through contact of knife circuit controller at block station A closed in the normal position, wire LFMK8 through contact of lever LFMK closed between the R and B positions, wire LFMK9 to coils of instrument LFMK, through another contact of lever LFMK, closed between the R and B positions, wire LFMK10 through front contact of relay 04TR, wire LFMK11 through front contact of relay 05TR, wire LFMK12 through front contact of relay 06TR, wire LFMK13 through front contact of relay 07TR, wire LFMK14 through contact of lever LFMK at block station B closed in the L position, through armature contact of instrument LFMK, closed when the lock is de-energized, wire LFMK15 through front contact of relay 08-09-010TPR to C. With this circuit completed it energizes the coils of instrument LFMK at A, thereby releasing lever LFMK so that it may be moved to the R position. This circuit is similar to the releasing circuit in Fig. 4 and, in addition, is controlled through contacts insuring that the switches leading to sidings are in normal position and locked before the apparatus at block station A can be released. With lever LFMK at block station A in the R position a circuit is completed from B through front contact of relay 01-02-03TPR, wire FMK1 through contact of signal lever 14 closed in the normal position, wire FMK2 through contact of lever of LFMK closed in the R position, wire FMK3 through contact of lever of FMK closed between B and D positions, to coils of instrument FMK to C.

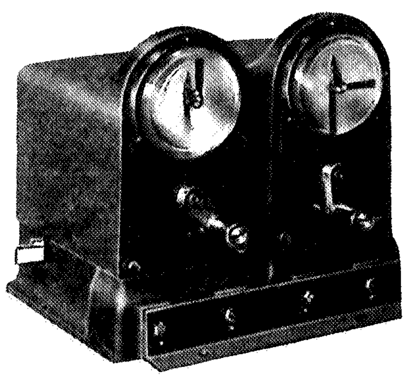

Fig. 7.
Interlocked Circuit Controllers.

As the lever of instrument LFMK was movεd to the R position it released the mechanical locking between lever LFMK and FMK and since the coils of instrument FMK are energized its lever can be moved to the R position. With lever FMK in the R position, lever contact which was closed between the B and D positions is opened, which de-energizes the coils of FMK and completes a circuit from B through armature contact of lever FMK closed when lock is de-energized, through contact of lever FMK closed in the R position, wire 14FL1 through lock magnet FL on lever 14, through latch contact of lever 14 to C. This releases signal lever 14 from its normal position allowing signal 14 to display a permissive or clear indication.

Assume a movement from eastward siding C to block station B instead of from A to B: it would be necessary for the signalman at A to secure an unlock from B as already explained, but instead of moving lever of instrument FMK to the R position it would be moved to the L position. Moving lever FMK to the L position completes a circuit from B through armature contact of FMK, closed when lock is de-energized, through contact of relay FMK closed in the L position, wire "C"WL1 through coils of electric lock "C"WL on switch C, wire "C"WL2 through contact of FMK closed in the L position to C. This will permit switch C to be unlocked and reversed, after which the movement can be made from siding C. It will also be noted that signal 14 at block station A is three-position and that the permissive indication can be displayed if necessary. A short track circuit is provided in advance of this signal, the same as was described in connection with signal 10 in Fig. 4. After a movement has been started from block station A to B it must be completed or clear of all track circuits between A and B before the signalman at A can release the instruments at B for a move from B to A. The circuits for this move are practically identical to those described in unlocking A from B and should be very readily traced.

Assume a train is moving from block station A to B and it is necessary for this train to enter siding at switch D. Traffic must first be established from block station A to B as previously described and when the train arrives at switch D it will stop on track circuit 07T, which will de-energize track relay 07TR. After the conductor of this train has called the signalman at block station B to unlock the siding switch, the signalman would move lever "D"L to the L position. This will complete a circuit from B through contact of "D"L closed in the L position, wire "D"WR3, through coils of relay "D"WR, wire "D"WR2 through contact of "D"L closed in the L position to C. This will energize polarized relay "D"WR and cause the polar contacts to be closed in the reverse position which will complete another circuit from wire "D"WR3, wire "D"WL3 through coils of electric lock "D"WL at switch D, wire "D"WL2 through back contact of relay 07TR, wire "D"WL4 through reverse polar and front neutral contacts of relay DWR to wire "D"WR2, through contact on hand circuit controller "D"L closed in the L position to C. This will permit the unlocking of switch D so that it can be reversed and movement made to the siding. After train has reported clear of the main track, switch closed and locked, it will again be locked by the signalman at B by "D"L being moved to the N position.

Should it be necessary to make a movement from siding through switch D to block station A the signalman at B would first establish traffic direction from B to A. After lever LFMK at B has been moved to the R position, lever FMK will be moved to the L position which would complete a circuit from B through armature contact of FMK, closed when lock is de-energized through lever contact of FMK closed in the L position, wire DWR1 through contact of "D"L closed between the N and R positions, wire "D"WR2 through coils of relay DWR, wire "D"WR3 through contact of "D"L closed between the N and R positions, wire "D"WR4 through contact of FMK closed in the L position to C. This will energize relay DWR and cause the normal polar contacts to close which will complete a circuit from wire "D"WR2 through front neutral and normal polar contacts of DWR, wire "D"WL1, wire "D"WL2 through coils of electric lock "D"WL at switch D, wire "D"WL3 to wire "D"WR3 through a contact of "D"L closed between the N and R positions, wire "D"WL4 through contact of FMK closed in the L position to C. Switch D can then be unlocked and reversed for movement to the main track, after which the train will hold traffic as long as it occupies any of the track circuits between block stations B and A.

The circuits for the complete control of the operating units at block stations A and B are not shown since they are similar to those previously described.

The circuits in Fig. 6 are for only one track. Should there be additional main tracks between block stations A and B which are operated under Controlled Manual Block System Rules, they would be arranged and controlled in a similar manner.

Various schemes of circuits other than those shown in this chapter are in use between block stations for Controlled Manual Block System Rules, but they are arranged to accomplish the same results, the main requisites of which are: continuous track circuits, the automatic release of signals to display their most restrictive indication, locking between block stations and outlying switches where trains or engines may enter or clear the block, indication locking to insure that signals display their most restrictive indication before signals for opposing movements are unlocked, and approach signals.

Certain installations are in service in which Controlled Manual Block System Rules are in effect for opposing movements and Automatic Block System Rules for following movements, in which case direction of traffic must be set up in much the same manner as just described, but after traffic has been established trains may follow each other on the same track the same as in automatic block system territory as described in Chapter XV—Automatic Block Systems.

FUNDAMENTAL THEORY OF DIRECT CURRENT

Elements

Nature of electricity.

Electricity is a weightless, invisible form of energy. We cannot accurately define it or state exactly what it is, so must study it by its effects. However, the laws governing certain of its actions are well understood.

That electricity is a form of energy is proven by its easy transformation into other forms of energy, such as heat, light, chemical and mechanical energy. For example, electrical energy which goes into the filament of a lamp bulb is radiated partly as heat and partly as light. It may be stored as chemical energy. For example, when it is fed into a storage battery. Furthermore, heat may be transformed into electricity. For example, if two wires of dissimilar metals are wrapped around each other for a short distance and their junction point is heated, an electric current will be caused to flow if the outward ends of the two wires are connected together. An example of reverse transformation is represented by the storage battery, where, on the charge part of the cycle, electricity is converted into chemical energy, which, on the discharge cycle, turns energy back to the circuit in the form of electricity. The advantage of electricity over the many other forms of energy is that it may be transmitted economically from point to point by the use of suitable conductors, thus making it a most satisfactory means of energy transmission over long distances.

Static electricity.

When electricity is at rest, in the form of an electric charge upon any surface or body, it is known as static electricity. It was known as early as 600 B.C. that when amber or jet was rubbed with a dry cloth it would attract certain light objects. Study upon this subject began in the middle of the Sixteenth Century. The electric charge was called "vis-electra," a Latin term meaning amber. In 1650 the word "electricity" appeared for the first time in print.

(a) *Attraction and repulsion.*

Many experiments were made during the Sixteenth and Seventeenth Centuries with static electricity and it was found that there were two kinds of electricity: *viz.*, positive and negative. According to modern theory, all matter is composed of two, and only two, constituents: namely, protons and electrons. Normally, every body contains equal numbers of protons and electrons, but it is possible to remove electrons from a body or add electrons to it. A body which contains unequal numbers of electrons and protons is said to be electrically charged. A body which contains more than its normal number of electrons is said to be negatively charged. A body which contains less than its normal number of electrons is said to be positively charged. Bodies with like electric charges repel each other; those with unlike charges attract. The force of attraction or repulsion between two charged bodies increases with the strength of the charges and the nearness of the bodies. The electric charge is found only on the surface of a body.

(b) Electrostatic induction.

When any material offers a high resistance to the flow of electricity, it is called an insulator, while any material offering little or no resistance is called a conductor. An insulating body such as a rod of glass or hard rubber holds its charge longer than a conducting body. A body having a positive charge and a body having an equal negative charge will have their charges neutralized if connected by a conductor or brought close enough together so that discharge can take place across the intervening air space. A bright spark is seen as the charges unite. When a charged body is placed near a neutral body, the charged body will induce a charge of opposite kind on the neutral body, and the charged body will then attract the other one in the same way that a magnet attracts a piece of soft iron. This phenomenon is called electrostatic induction. Charged bodies are surrounded by an electric field just as a magnet is surrounded by a magnetic field and their actions upon neutral bodies are similar.

(c) The Leyden jar—condensers.

Before the invention of batteries and electromagnetic generating machines, electrostatic machines with rotating glass plates were developed to produce electric charges by friction. During this period a piece of apparatus to receive and store the electrical charges was developed. This storage reservoir, the Leyden jar, is a wide-mouthed glass jar coated on the inside and outside with tinfoil about two-thirds its height. Through an insulating stopper in the mouth of the jar is a metal rod with a brass knob on the top end and a suspended chain from the lower end which touches the tinfoil coating. All the parts between the tinfoil inside and outside are shellacked to guard against moisture. Moisture would permit the electrostatic charge to leak over the glass from the inner to the outer tinfoil. The Leyden jar is charged by connecting the outside knob to the electrical charging machine, while the outside tinfoil on the jar is connected to ground; one side of the electrical machine is also connected to ground. When positive electricity from the rotating glass plates of the machine is presented to the metal knob of the jar, the inside tinfoil becomes positively charged and the outside tinfoil layer is negatively charged. The amount of electric charge which the jar will carry increases with the size of the jar and its tinfoil coating. The larger the jar with its larger amount of tinfoil and the thinner the glass wall between the tinfoil coatings, the greater the amount of electric charge that may be stored; if the charge becomes too great, the electric stress on the glass between the two tinfoil layers becomes excessive and an electric spark will puncture the glass. Consisting simply of two parallel layers of tinfoil highly insulated from each other, the Leyden jar is a rather cumbersome form of condenser and not nearly so convenient as the modern condensers used in radio and other electrical apparatus.

(d) Lightning.

Lightning and the spark that travels from one coating to the other of a Leyden jar, were discovered to be of the same phenomena.

Dynamic electricity.

When electricity is in motion, as, for example, in the case of electric currents flowing in a circuit, it is known as dynamic electricity. The Voltaic pile, discovered in 1796 by Volta, the Italian physicist, produced the first sustained current of electricity. The Voltaic pile consisted of a number of alternate copper and zinc discs piled vertically one on top of the other with a thin layer of felt or other porous insulating material between each copper and each zinc disc. The pile when immersed in a solution of salt or vinegar caused current to be produced by chemical action. The Voltaic pile is the forerunner of our present-day batteries. This Voltaic (or dynamic) electricity was discovered to be the same as static electricity, for it was found possible to store charges from the Voltaic pile in a Leyden jar.

Difference of potential—voltage.

To cause an electric current to flow through a conducting body, there must be a difference of electrical potential and a complete circuit connecting the two points where the difference of potential exists. The highest point of potential will be termed "positive" and the lowest point "negative." This potential difference is the electrical pressure known as electromotive force (e.m.f.) or voltage; naturally, the greater the potential difference the greater will be the voltage or electromotive force. The electromotive force is measured with a voltmeter. The voltage of an ordinary caustic soda cell is about 0.7 volt, while that of a dry cell is 1.5 volts. The third-rail voltage, used on electric propulsion roads, usually is from 550 to 650 volts; where alternating current is used for electric propulsion the difference of potential or voltage between the overhead catenary and the rails is 11,000 volts, while on roads using direct current propulsion with an overhead catenary, the voltage is from 1500 to 3000 volts. The third-rail or the catenary is the positive conductor in direct current systems; the track is the negative conductor.

Conductors and insulators.

The conducting body that carries the current is the electric conductor. Every material has a certain conductance and resistance to the flow of an electric current. If it has good conductance it has low resistance, that is, it offers very little obstruction to the flow of current, and is called a conductor. On the other hand, if it offers a great amount of obstruction to the flow of current, it is called an insulator. The resistance to the flow of current is measured in ohms or fraction of an ohm. One thousand feet of No. 10 A.W.G. copper wire offers about 1 ohm resistance.

Conductors.

Following is a list of typical conductors and their approximate conductivities, taking silver as a standard of 100 per cent conductivity:

Silver	100.00	Steel	12.00
Copper	99.90	Copper, 10 per cent nickel	10.60
Gold	78.00	Lead	8.88
Aluminum	64.50	Bronze, 20 per cent tin	8.40
Telephonic bronze	35.00	Nickel	7.89
Copper, 10 per cent bronze	30.00	Phosphor bronze, 10 per cent tin	6.50
Zinc	29.90	Antimony	3.88
Brass, 30 per cent zinc	21.50	Mercury	1.60
Phosphor tin	17.70	Charcoal	Variable
Platinum	18.00	Acid solutions	Variable
Soft iron	16.80	Saline solutions	Variable
Swedish iron	16.00	Water	Variable
Pure tin	15.45	Human body	Variable
Aluminum bronze	12.60		

Partial Conductors or Insulators

Cotton
Dry wood
Marble
Paper

Insulators.

Following is a list of typical insulators:

Dry air	Mica
Shellac	Ebonite
Paraffin	Gutta-percha
Amber	Rubber
Resins	Silk
Sulphur	Dry paper
Wax	Parchment
Jet	Dry leather
Glass	Porcelain
Bakelite	Oils

Insulating properties greatly depend on whether the material is dry or wet. Some materials make very good insulators when dry, but become partial conductors when wet; impurities may also materially affect their insulating value.

Batteries

Batteries are described in Chapter V—Batteries.

Electrolysis

Electric currents decompose water when it contains acids or metallic salts; the action is called electrolysis. It is the reverse of the action in a primary cell and corresponds to the charging cycle of a storage cell. The principle of electrolysis is applied commercially in electroplating to form a coating of one metal upon another. Water mains, gas mains, lead coverings of cables, or any underground metal line acting as an electrical conductor for a negative return current, may become corroded by electrolysis in the presence of moisture, where the current leaves the negative return conductor to enter the earth path to the negative pole of the generator.

Magnetism

Nature of magnetism.

Any substance possessing the property of attracting pieces of iron or steel, and when freely suspended, of taking a definite position with respect to the North and South Poles of the earth, is a magnet. Ancient civilization was familiar with the properties of the natural magnet, a metallic mineral, then known as lodestone. A Roman author writing about 50 B.C. stated that the name Magnes for loadstone was derived from Magnesia, a district in Asia Minor, where the ore occurred plentifully. Lodestone, but not always having magnetic properties, is an oxide of iron found in many parts of the earth.

Artificial magnets.

An artificial magnet is made by rubbing a piece of hard steel with lodestone. Artificial magnets can be made stronger than natural magnets, and are used instead of natural magnets. When a magnet is freely suspended, the north-seeking end is called the north pole of the magnet, and the south-seeking end the south pole. The attractive power of a magnet is greatest at its poles, diminishing toward its center, where its attractive power ceases. If a magnet be broken into several pieces, each piece will become a separate magnet, but its power of attraction is proportional to its size, tending to show that each particle of the material is a separate magnet.

Attraction and repulsion of magnets.

If the north pole of a magnet be brought near the north pole of another, there will be repulsion between the poles. There will also be repulsion if a south pole be brought near another south pole, but if a north pole be brought near a south pole there will be an attraction. Like poles repel, unlike poles attract.

Magnetic field.

Around each magnet, there is a magnetic field which consists of magnetic lines of force. These lines of force can be made apparent by means of iron filings scattered on a piece of paper placed over a magnet, the paper being tapped slightly to allow the filings to form themselves along the lines of force. Figures 8 and 9 show this for a bar magnet and a horseshoe magnet, respectively.

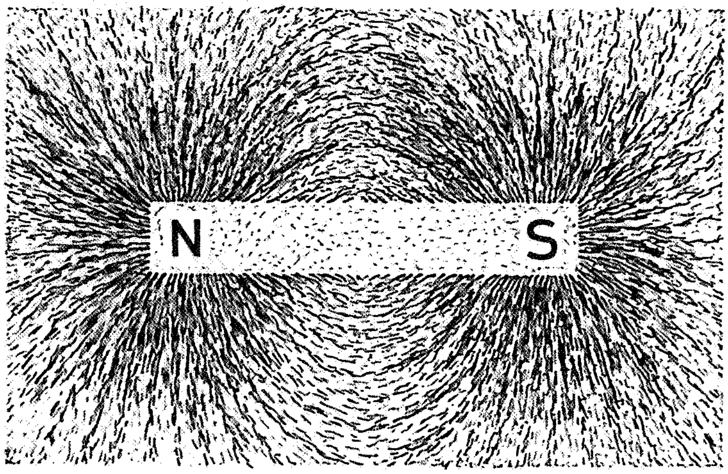

Fig. 8.
Bar Magnet.

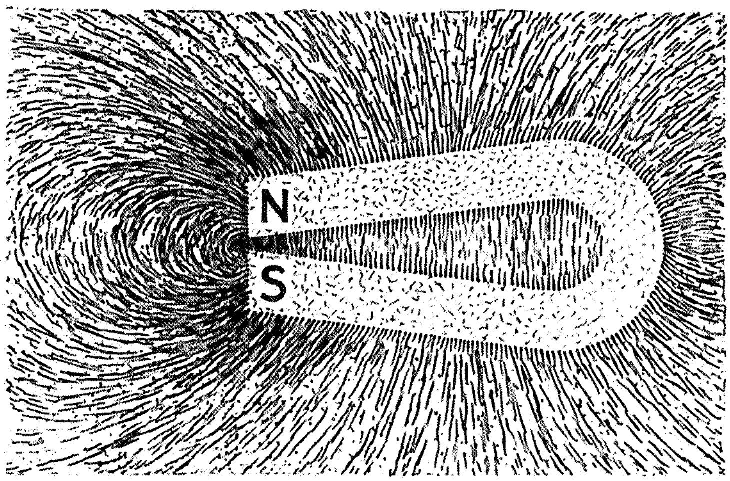

Fig. 9.
Horseshoe Magnet.

Flux.

All the lines of force in any stated area are called flux, and the number of lines of force per unit area, say per square inch, is called the field intensity, or flux density. The magnetic flux possesses a mechanical tension along its own direction, and a mechanical pressure at right angles to the direction of the lines of force. Flux lines therefore tend to shorten themselves.

Magnetic substances.

When a body is placed within a magnetic field and becomes an artificial magnet, it is called a magnetic substance. Some substances retain their magnetism only while under the influence of the field, others retain their magnetic properties when removed from the field, and are called permanent magnets. The magnetism remaining in a magnetic substance after it is removed from the magnetic field is called residual magnetism. Permanent magnets lose their magnetism if subjected to knocks or jars or very high temperatures.

Relation between the electric current and the magnet.

There is a close relation between the electric current and magnetism. In 1820 it was discovered that a magnetic field surrounded a wire carrying a current of electricity; the nearer the wire, the stronger the magnetic field. It was noted that a magnetic needle, freely suspended parallel to a wire carrying a current of electricity, would be deflected to the right or left, depending upon the direction of flow of the current in the wire. The amount of deflection depends upon the strength of the magnetic field around the wire, (that is, upon the current, which produces the magnetic field) the length of the magnet and the strength of its poles.

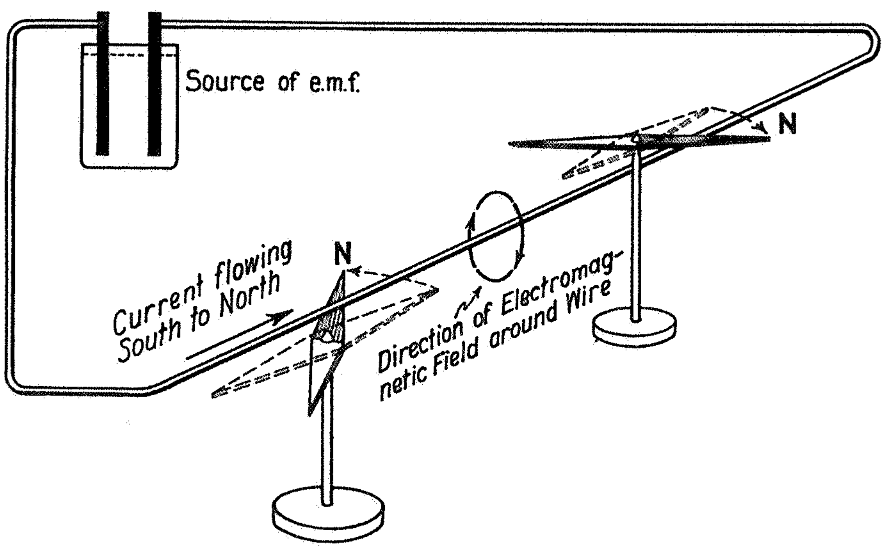

Fig. 10.
Deflection of a Magnetic Needle by a Current Flowing through a Wire.

In a wire running north and south, shown in Fig. 10, a current is assumed to flow from south to north. A magnetic needle beneath the wire will have its north-seeking pole deflected towards the west; under the same conditions of current flow, a magnetic needle placed above the wire will have its north-seeking pole deflected toward the east. Reversing the direction of current flow reverses the direction of deflection of the magnetic needle in both cases.

Solenoid.

A coil of wire wound in the form of a helix or tube is called a solenoid. See Fig. 11. If a current flows through a solenoid, an electromagnetic field is developed while the current flows, and if the solenoid is freely suspended it will assume the same position relative to the earth that a magnetic needle would assume. The polarity of the solenoid depends only on the direction of current flow through its turns and not on the direction of winding. Reverse the direction of current flow and the polarity of the solenoid also reverses. Stop the flow of current and the solenoid loses its magnetic properties. Polarity is determined as follows: face one end of the solenoid; if the direction of current flow is clockwise the near end of the solenoid is the south pole; if counter-clockwise, the near end is the north pole.

The magnetic field of a solenoid is strongest within its coils. If a plunger of soft iron be partially inserted in a solenoid which is carrying a current, the plunger will be drawn into the solenoid by magnetic induction. The solenoid can therefore be used to do mechanical work, such as to operate a signal arm, to operate the feeding mechanism in arc lamps, to automatically open switches in electric circuits when the current becomes excessive, as in the circuit breaker, to close switches at a distance for remote control purposes, etc.

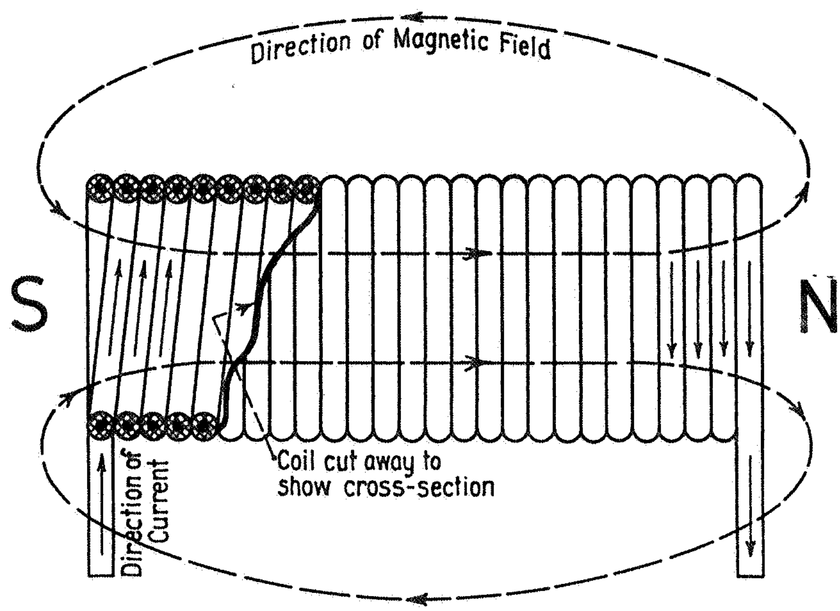

Fig. 11.
Solenoid.

Electromagnets.

An electromagnet is a device comprising one or more coils of insulated wire wound around an iron or steel core, and depending for its magnetic action upon the passage of an electric current through the wire. See Fig. 12. The iron core is a magnet, due to magnetic induction, only while the current is flowing. Electromagnets are generally of horseshoe- or U-shape, like those in signal relays. The winding of the turns must be such that if the magnet were straightened out the turns would form a continuous solenoid. The ends of horseshoe-shaped magnets have opposite polarity. Electromagnets are used extensively in telegraphy, telephony, railway signaling, and numerous other fields.

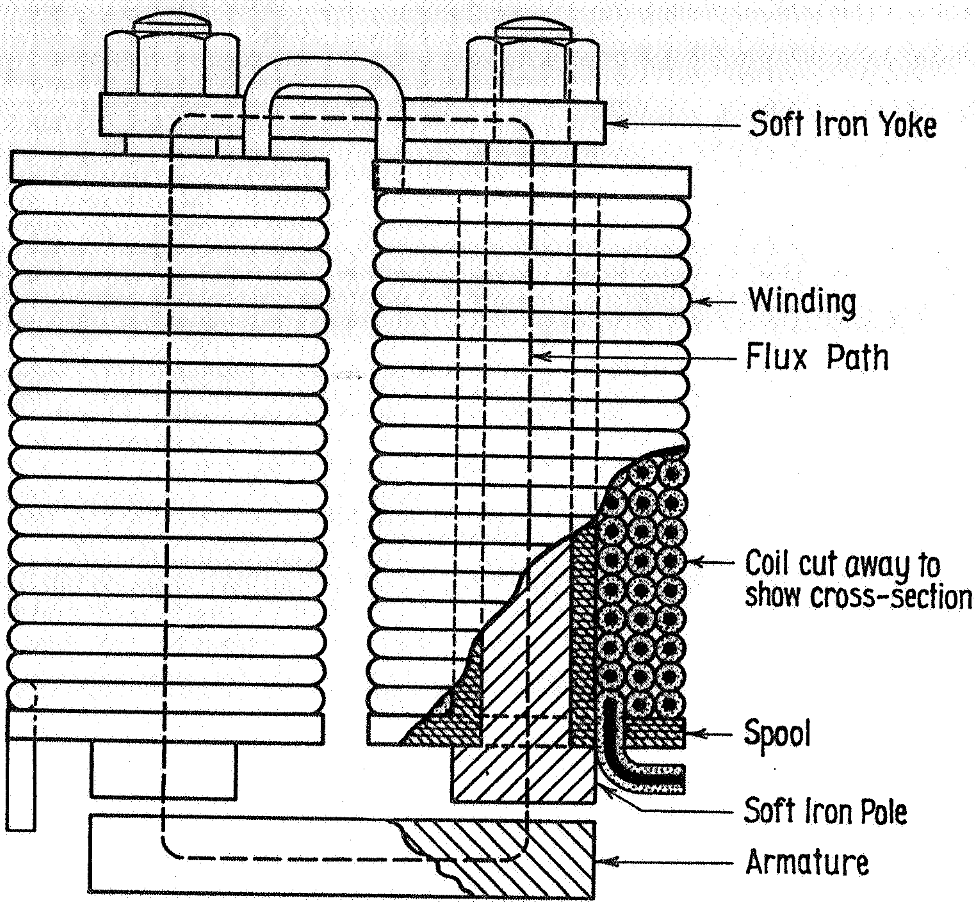

Fig. 12.
Electromagnet.

Electromagnetic induction.

It is a fundamental fact that when an electrical conductor, such as a wire, is moved across a magnetic field, see Fig. 13, so as to cut magnetic lines of force, an electromotive force is generated in the moving conductor, and if the moving conductor is part of a closed electric circuit, an electric current will flow. The strength of the e.m.f. so generated is proportional to the strength of the magnetic field and to the speed at which the conductor is moved; or more simply, the voltage varies with the rate at which magnetic lines of force are cut. No explanation is available as to why an e.m.f. should be generated when a conductor cuts across a magnetic field. All that is known is that an e.m.f. is generated. If the conductor is formed into a loop and is held stationary in the magnetic field at an angle to the magnetic lines of force, and the flux density of the magnetic field is varied, an e.m.f. will be generated in the loop proportional to the rate at which the number of lines of force enclosed within the loop is changing, and to the number of turns in series in the loop, if the conductor was made into a loop of more than one turn. The maximum e.m.f. generated by a given change in flux density will occur when the plane of the loop is at right angles to the direction of the magnetic lines of force, for then the loop will enclose the maximum number of lines. Sudden removal of the magnetic field will also produce a momentary e.m.f. in the loop. By rotating the loop in a magnetic field, as shown in Fig. 14, the number of magnetic lines of force threading the loop will change continuously and an e.m.f. will be generated in the loop. This is the principle of the dynamo or electric generator.

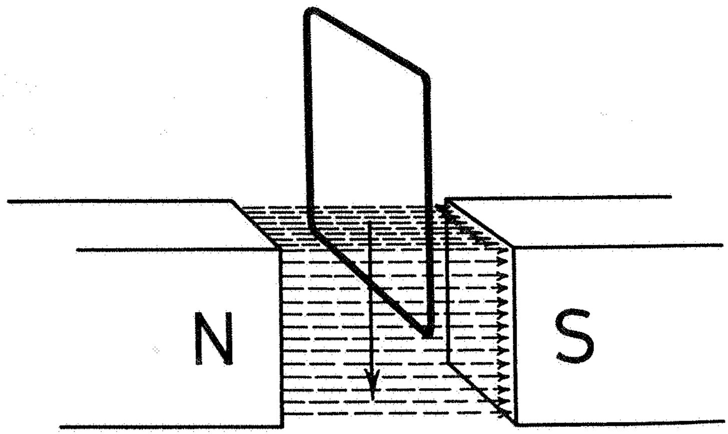

Fig. 13.
Conductor Cutting Magnetic Lines of Force by Passing Loop Across the Magnetic Field.

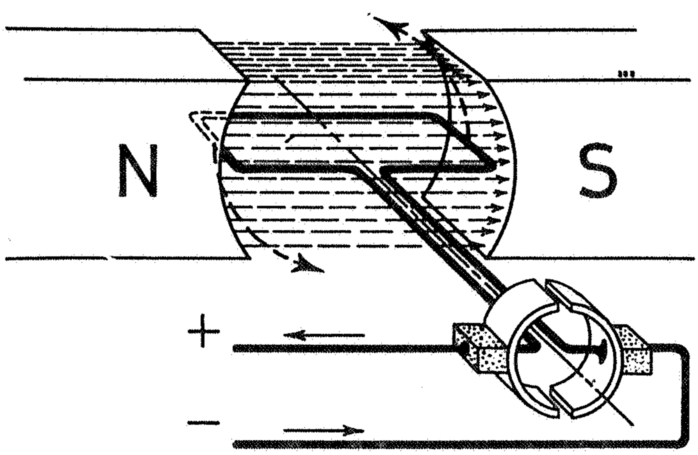

Fig. 14.
Conductor Cutting Magnetic Lines of Force by Revolving on an Axis in the Magnetic Field.

Due to its magnetic field, a coil carrying a current will, on being inserted into another coil, produce an e.m.f. in that coil, the same as would be produced if a permanent magnet were inserted into the coil so that the turns of the coil cut the magnetic lines of force of the magnet. Detailed information on this subject is given in Fundamental Theory of Alternating Currents appearing in Chapter IX—Rectifiers.

Induction coils.

If two coils are in independent electric circuits and one coil is placed inside of the other, and an increasing and decreasing current is caused to flow in, say, the inner coil, a fluctuating magnetic field will be produced around the inner coil proportional to the current flowing and to the number of turns in the coil. These magnetic lines of force also link with the turns of the outer coil, and, as they grow and die, will cut the turns of the outer coil and generate an e.m.f. in it, whether the circuit of the outer coil is closed or open. The induced e.m.f. will be proportional to the rate of change of magnetic lines of force and to the number of turns in the outer coil. If the outer circuit is closed, the induced e.m.f. will cause a current to flow. The direction of the induced e.m.f. will be opposite to the direction of the e.m.f. of the inner coil when the current in the inner coil is increasing, and in the same direction when the current is decreasing. No electromotive force will be induced when the flow of current in the inner coil is constant. Ordinarily in direct current work, the condition of a changing electromagnetic field will occur only when the inner coil circuit is closed and opened. The combination of two such coils, with a device to continuously interrupt the current in the inner coil, is called an induction coil, and is used to produce high e.m.f.'s or voltages. The action of the induction coil is the basis of the transformer. The coil which produces the changing electromagnetic field is termed the primary coil, and the coil in which the e.m.f. is induced is termed the secondary coil. In the foregoing discussion the inner coil was chosen as the primary merely for illustration. The action is the same whether the primary is placed on the inside or the outside of the combination.

Self-induction and mutual induction.

The electromagnetic field surrounding a coil due to a current flowing in the coil will increase and decrease as the current is increased and decreased. The magnetic lines of force, as they change with the current producing them, will cut across the turns of the coil and induce in the coil an e.m.f., called a counter or back e.m.f., proportional to the rate of change of current and to the number of turns in series in the coil. When the current is increasing, the counter-e.m.f. opposes and when it is decreasing the counter-e.m.f. assists the e.m.f. which causes the current to flow through the coil. This is termed self-induction.

If two coils are adjacent but in independent electric circuits, and the lines of force of the electromagnetic field due to a changing current in one coil cut the turns of the adjacent coil, then an e.m.f. will be induced in the adjacent coil. The direction of the induced e.m.f. in the adjacent coil will be opposite to the direction of the e.m.f. in the field-producing coil when the current is increasing, and in the same direction when the current is decreasing. This is termed mutual induction.

Unit of self-inductance.

When current is caused to change uniformly at the rate of 1 ampere per second and the counter-electromotive force is 1 volt, then the coefficient of self-induction of the coil is said to be 1 henry. The henry is the practical unit of self-inductance and is designated by the letter L.

Unit of mutual inductance.

When the current in the field-producing coil is made to change uniformly at the rate of 1 ampere per second and the induced e.m.f. in the adjacent coil is 1 volt, then the coefficient of mutual induction of the adjacent coil is said to be 1 henry. The henry is the practical unit of mutual inductance and is designated by the letter M.

It should be noticed that the phenomena of self-induction and mutual induction occur only in the presence of a changing electromagnetic field and do not exist when the current is flowing uniformly in one direction. In direct current circuits these effects are momentary, occurring when the circuit is closed and opened.

Units of Measurement for Current, Voltage and Resistance

Unit of current.

Current is the rate of flow of electricity in a completed circuit between two points having a difference of potential and is expressed in amperes. The ampere, the practical unit of current, is defined as being that value of current which, when flowing in a conductor that is lying in a magnetic field of one line per square centimeter, at right angles to the lines of force, causes each centimeter length of that conductor to be acted upon by a force of one-tenth dyne. It is also defined as the current produced by an electromotive force of 1 volt in a circuit having a resistance of 1 ohm. A milliampere is one one-thousandth of an ampere. The designation for current is the letter I.

Unit of electromotive force or voltage.

Electromotive force is the electrical pressure or difference of electric potential, tending to cause an electric current to flow in a closed circuit and is expressed in volts. The volt, the practical unit of e.m.f., is defined as being the e.m.f. generated in a conductor when that conductor is cutting magnetic lines of force at the rate of one hundred million lines per second. It is also defined as the unit of electromotive force that, when impressed on an electrical conductor whose resistance is 1 ohm, will produce a current of 1 ampere. A millivolt is one one-thousandth of a volt; a kilovolt is one thousand volts. The designation for electromotive force or voltage is the letter E.

Unit of resistance.

Resistance is the opposition offered by a substance or body to the passage through it of an electric current. The ohm, the practical unit of resistance, is, by Ohm's law, defined as being the resistance of a circuit through which an e.m.f. of 1 volt will cause a current of 1 ampere to flow. A microhm is one one-millionth of an ohm; a megohm is one million ohms. The designation for resistance is the letter R.

International units.

In the International system of units the definitions are as follows:

An ampere is defined as being that rate of flow of electric current that will deposit silver from a standard silver nitrate solution at the rate of 0.001118 gram per second.

An ohm is defined as being the resistance offered to a constant electric current by a column of mercury, at zero degree Centigrade, 106.3 centimeters long, weighing 14.4521 grams, and having a constant cross-sectional area.

A volt is, by Ohm's law, defined as being the amount of e.m.f. that will drive a current of 1 ampere through a resistance of 1 ohm.

The international units were developed with the idea that they would be simpler and capable of more accurate reproduction than the practical units based on the centimeter-gram-second (c.g.s.) system, and they were adopted by an International Congress in 1893. At the present time, however, the c.g.s. units can be reproduced with greater accuracy than the international units, and the great standardizing laboratories of the world base their measurements upon the c.g.s. system.

Wires and Cables

Unit of wire measurement.

The unit of wire measurement is the circular mil (c.m.). A cylindrical wire one one-thousandth of an inch in diameter is said to have a cross-sectional area of one circular mil. One thousand such wires laid side by side would form a layer one inch wide, and one one-thousandth of an inch thick. One thousand such layers piled on each other would make a pile one inch square, containing one million wires with a total cross-sectional area of one million c.m. This total cross-sectional area of one million c.m. is equal to the cross-sectional area of a solid cylindrical wire one inch in diameter. Putting it another way, the circular mil area of any solid wire is equal to the area of the number of wires one one-thousandth of an inch in diameter which could be placed in a square drawn around a circle having the same diameter as the single solid wire.

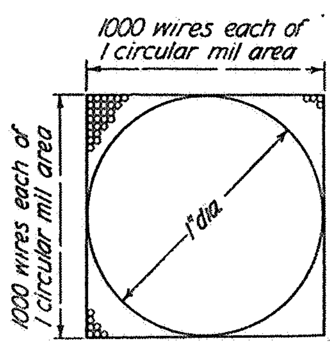

Fig. 15.
Relation Between Cross-Sectional Area of a Conductor and its Circular Mil Area.

If the diameter of a wire in mils is squared the result is the c.m. area. Taking, for example, No. 0000 wire, A.W.G., the diameter is 0.4600 inch or 460.0 mils, and 460.0 x 460.0 = 211,600 c.m. (In the Working Wire Table this c.m. area is shown rounded off to 212,000.)

Figure 15 shows the relation between one million wires each of one c.m. area and a single solid wire having an area equivalent to the combined area of the million small wires.

Resistance, and specific resistance or resistivity.

Resistance has been defined as the opposition of any substance to the flow of an electric current through it. Experiment shows that the resistance of a conductor is directly proportional to its length and inversely proportional to its cross-sectional area. If a cable one mile long has a known value of resistance, then one-half mile of the cable will have half, and two miles of the cable will have twice, that resistance; the cross-sectional area and the material of the cable being assumed to remain constant throughout its length. If the cable one mile long of known resistance has a cross-sectional area of one-half square inch, then a similar cable one mile long but having twice the cross-sectional area or one square inch will have only one-half of the resistance; and a similar cable with one-half the cross-sectional area or one-quarter square inch will have twice the resistance. Hard-drawing of wire increases its resistance slightly; annealing decreases it. Impurities in the conductor material also increase the resistance. The resistance of metallic conductors increases with increase in temperature. When stating a resistance value, therefore, it is essential that the temperature of the conductor material assumed in the calculation of resistance be stated. In practice, an arbitrary value is chosen to represent the average temperature over the normal range.

The general expression of the formula for resistance is

$$\text{R, resistance of wire} = \frac{\text{(a constant)} \times \text{length of wire}}{\text{cross-sectional area of wire}}.$$

The constant is known as the specific resistance or resistivity and depends upon the material and upon the units of length and area chosen. If centimeter units are used, the specific resistance is the resistance offered by a piece of the material one centimeter long and one square centimeter in cross-section and is expressed in ohms per centimeter cube. In practice, the unit of cross-sectional area most generally used is the circular mil. When the circular mil is used as the unit of cross-sectional area, the foot is generally used as the unit of length. The specific resistance of pure annealed copper is 10.575 ohms per circular mil-foot, at 25 degrees Centigrade (77 degrees Fahrenheit). A circular mil-foot is a cylinder one mil or one one-thousandth of an inch in diameter and one foot long. The formula for resistance based on the circular mil-foot, at 25 degrees Centigrade, is

$$\text{R, resistance of wire in ohms} = 10.575 \times \frac{\text{length of wire in feet}}{\text{c.m. area of wire}}.$$

For example, No. 0000 wire, A.W.G., has an area of 211,600 c.m and the resistance of 1000 feet of wire at 25 degrees Centigrade is

$$10.575 \times \frac{1000}{211{,}600} = 0.04998 \text{ ohm.}$$

(In the accompanying Working Wire Table such a high degree of accuracy is not required and the values for c.m. area and resistance of No. 0000 wire have been rounded off to 212,000 and 0.0500, respectively.)

Conductance, and specific conductance or conductivity.

The conductance of a wire is defined as being the reciprocal of its resistance. The unit of conductance is the mho (ohm spelled backward). A wire of 1 ohm resistance has a conductance of 1 mho; a wire of 2 ohms resistance has a conductance of ½ mho, etc. Conductance varies directly as the cross-sectional area of a conductor and inversely as the length. The general expression of the formula for conductance is

$$G\text{, conductance in mhos} = \frac{(\text{a constant}) \times \text{cross-sectional area of wire}}{\text{length of wire}}.$$

The constant is known as the specific conductance or conductivity and depends upon the material and upon the units of length and area chosen. The specific conductance is the reciprocal of the specific resistance.

Volume-conductivity and mass-conductivity.

In practice, conductivities are used only to compare one conductor material with another. It is therefore convenient to chose one material as the standard and to compare others with it. Accordingly, pure annealed copper has been chosen as the standard and its conductivity is taken as being 100 per cent.

Conductive materials may be compared on either an equal-volume basis or an equal-mass basis. If the resistance per circular mil-foot of a given material is four times that of copper, at the same temperature, its volume-conductivity is said to be 25 per cent, and the cross-sectional area of a conductor made of this material would need to be four times as great as it would be if made of copper, in order to have as low a resistance. Where space is the prime consideration, as in the slots of a generator or motor, volume-conductivities are useful. In the case of transmission lines, however, the space is not limited, and, as conductors are purchased by the pound, the conductor materials are compared on an equal-mass basis. If the resistance of a uniform wire, of a given material, one metre long and weighing one gram, is twice the resistance of a uniform wire of pure annealed copper one metre long and weighing one gram, at the same temperature, its mass-conductivity is said to be 50 per cent, and it is necessary to purchase twice as many pounds of that material as of copper in order to have as low a resistance in the transmission line. The term "conductivity" as commonly used in reference to conductors refers to the "per cent mass-conductivity" of the material and not to its "specific conductance or conductivity."

WORKING TABLE, STANDARD ANNEALED COPPER WIRE AT 25 DEGREES CENTIGRADE (77 DEGREES FAHRENHEIT).

American Wire Gage

Gage No.	Diameter in Mils	Cross Section, Circular Mils	Ohms per 1000 feet
0000	460.	212 000.	0.0500
000	410.	168 000.	.0630
00	365.	133 000.	.0795
0	325.	106 000.	.100
1	289.	83 700.	.126
2	258.	66 400.	.159
3	229.	52 600.	.201
4	204.	41 700.	.253
5	182.	33 100.	.319
6	162.	26 300.	.403
7	144.	20 800.	.508
8	128.	16 500.	.641
9	114.	13 100.	.808
10	102.	10 400.	1.02
11	91.	8230.	1.28
12	81.	6530.	1.62
13	72.	5180.	2.04
14	64.	4110.	2.58
15	57.	3260.	3.25
16	51.	2580.	4.09
17	45.	2050.	5.16
18	40.	1620.	6.51
19	36.	1290.	8.21
20	32.	1020.	10.4
21	28.5	810.	13.1

(From United States Bureau of Standards Circular No. 31 [3rd Edition].)

Notes:

The term "standard" copper refers to the International Annealed Copper Standard (set up by the International Electrotechnical Commission in 1913), which has a density of 8.89 at 20 degrees Centigrade and a conductivity of 100 per cent.

The values shown in the second, third and fourth columns of the above table are the exact values rounded off.

Since the American Wire Gage is formed by geometrical progression, the wire table is easily reproduced from the ratio of any diameter to the diameter of the next greater number and one of the sizes as a starting point. The resistance, mass, and cross-section vary with the square of the diameter, hence by the use of the square of the ratio of one diameter to the next, *viz.*, 1.2610, it is possible to deduce the resistance, mass, or cross-section of any size from the next. This number may be carried in the mind as approximately 1¼. Furthermore, since the cube of this number is so very nearly 2., (actually 2.005), it follows that every three gage numbers the resistance and mass per unit length and also the cross-section are doubled or halved.

The effect of change in temperature on the value of resistance.

The resistance of a conductor varies with its temperature; therefore it is necessary to establish a datum of reference. The standard reference temperature for resistance and conductivity measurements is 20 degrees Centigrade (68 degrees Fahrenheit). Wire tables are compiled for 20 degrees Centigrade and converted for other temperatures. The resistance values given in the above table may be converted for temperatures other than 25 degrees Centigrade (77 degrees Fahrenheit) by means of the following formula:

If C = per cent mass-conductivity;

R_{77} = resistance of a wire of 100 per cent mass-conductivity at 77 degrees Fahrenheit, as per Working Table;

t = temperature in degrees Fahrenheit;

and R_t = resistance of a wire of C per cent mass-conductivity at t degrees Fahrenheit;

then $$R_t = R_{77}\left[\frac{100}{C} + 0.00214(t-77)\right]$$

Calculation of Circuits—Ohm's Law

Relation of current, voltage and resistance in a circuit.

The law governing the flow of current in a closed circuit is known as Ohm's law, which states that in a closed circuit the current is directly proportional to the electromotive force, and inversely proportional to the resistance of the circuit, when the temperature is constant. This relation is expressed as—

$$I = \frac{E}{R} \quad \text{or} \quad R = \frac{E}{I} \quad \text{or} \quad E = IR$$

where E = the electromotive force, in volts;

I = the current, in amperes;

R = the resistance, in ohms.

Resistance in series.

The resistance of a circuit that has several resistances in series is equal to the sum of the separate resistances. See Fig. 16. If R represents the circuit resistance, then

$$R = R_1 + R_2 + R_3$$

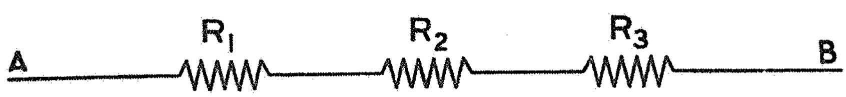

Fig. 16.
Resistances in Series.

Resistances in multiple.

When resistances are connected in multiple, as shown in Fig. 17, it is seen that the current has three paths to flow through. If the resistances are equal, one-third of the total current will flow in each of the three similar paths. From this, it is seen that the total conductance of a circuit is equal to the sum of the conductances of the various paths, or, since the conductance is the reciprocal of the resistance,

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3} \text{ or } R=\frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}=\frac{R_1\times R_2\times R_3}{R_2R_3+R_1R_3+R_1R_2}$$

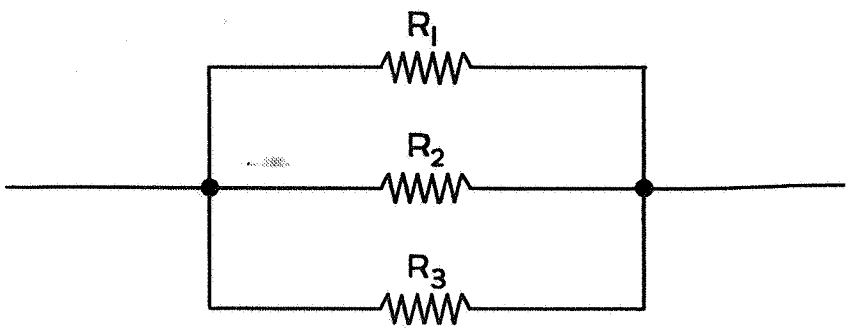

Fig. 17.
Resistances in Multiple.

Resistances in multiple-series.

When resistances are arranged in multiple-series, the total resistance is found by first adding the separate resistances in series in each branch to find the resistance of the various branches, and then calculating the various branches in multiple. The value of the resultant resistance for the multiple-series arrangement shown in Fig. 18 is 16 ohms.

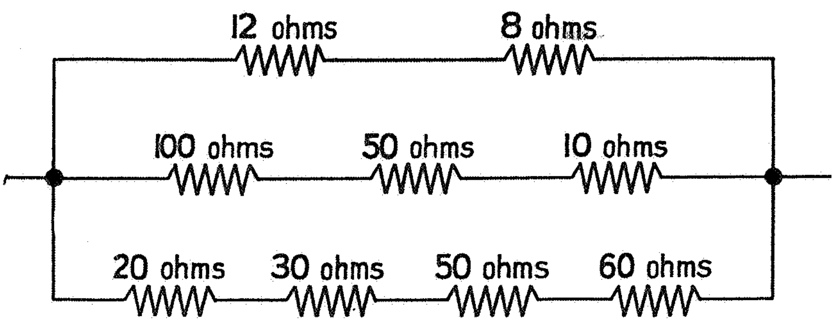

Fig. 18.
Resistances in Multiple-Series.

Use of voltmeter.

The electromotive force between any two points of a circuit is measured with a voltmeter. The positive lead of the voltmeter is connected to the

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positive of the circuit, and the negative lead to the negative of the circuit as shown in Fig. 19, where voltmeter V_1 measures the electromotive force across the generator G and voltmeter V_2 measures the electromotive force or voltage drop across the resistance R.

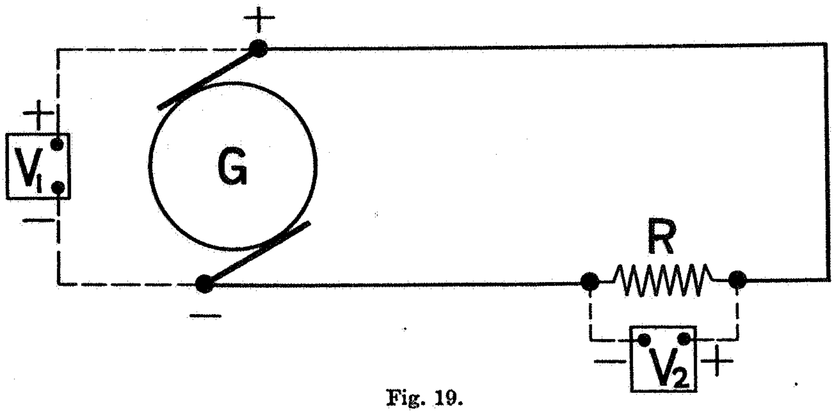

Fig. 19.
Method of Using Voltmeter.

Use of ammeter.

When the current in a circuit is to be measured, the ammeter is connected in series in the circuit as shown in Fig. 20.

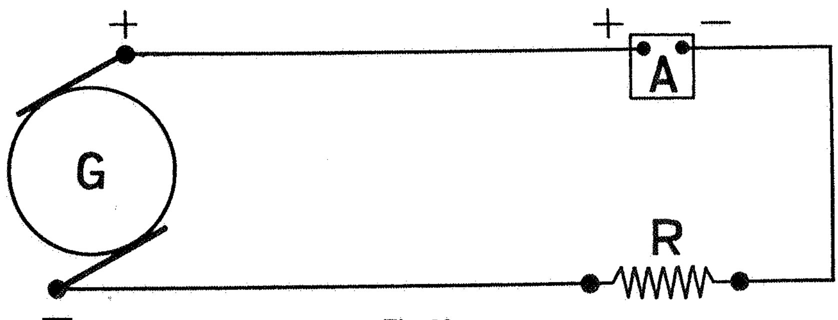

Fig. 20.
Method of Using Ammeter.

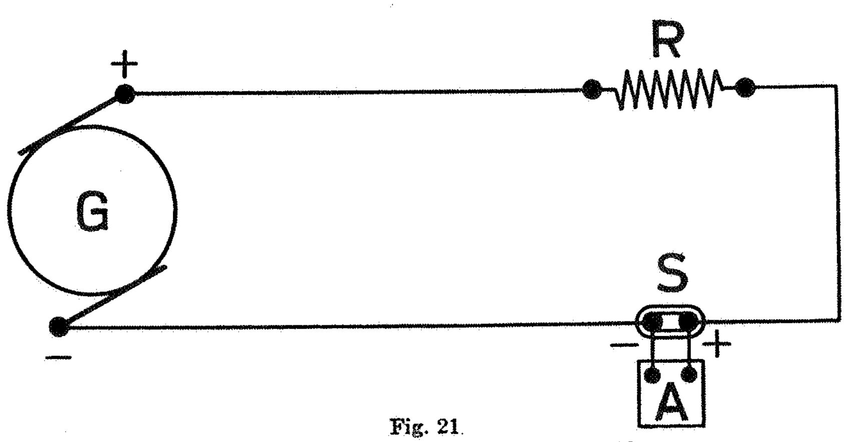

Fig. 21.
Method of Using Ammeter with External Shunt.

When the amount of current to be measured is very large, a very cumbersome and expensive ammeter would be required. To overcome this difficulty external shunts are provided, the shunt being a conductor having a current-carrying capacity at least equivalent to the maximum reading of the ammeter to which it belongs. The shunt is inserted in the circuit, while the leads of the ammeter span the shunt S, as shown in Fig. 21.

Voltage drop in a circuit with several resistances in series.

In Fig. 16, the electromotive force which would be required between points A and B to cause 2 amperes to flow through the circuit, would be calculated as follows:

Assume resistances R_1, R_2 and R_3 to be 50 ohms, 100 ohms and 80 ohms, respectively. The drop across R_1 is $50 \times 2 = 100$ volts, across R_2 is $100 \times 2 = 200$ volts and across R_3 is $80 \times 2 = 160$ volts, or a total of 460 volts.

Voltage drop in a circuit with resistances in multiple.

Referring to Fig. 22, a 110-volt battery is furnishing energy for two circuits, R_1 of 10 ohms and R_2 of 20 ohms. The internal resistance of the battery is low and will be considered as zero in this calculation. The resistance of each of the conductors between the battery and R_1 is ¼ ohm, and that of each of the conductors between R_1 and R_2 is ½ ohm. As the battery current flows along the conductors it causes a voltage drop, and assuming that the apparatus represented by R_1 and R_2 will operate on a minimum voltage of 95, the problem is to find whether we will have sufficient voltage at AB and CD to operate the apparatus R_1 and R_2 connected across the conductors at these two points.

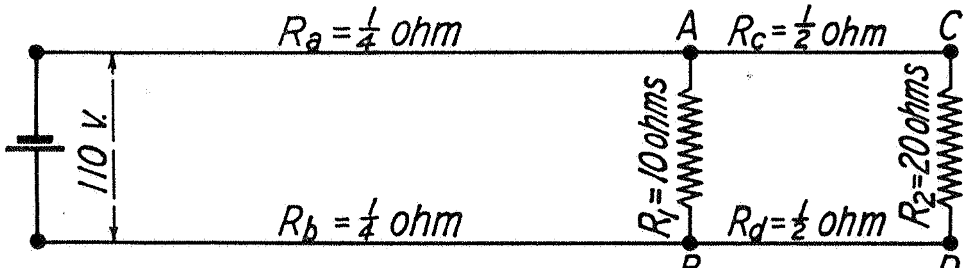

Fig. 22.
Voltage Drop in a Circuit with Resistances in Multiple.

First, the resistance of the branch of the circuit containing R_2 consists of R_2 of 20 ohms and conductor resistances R_c and R_d of ½ ohm each, this branch therefore having a total resistance of 21 ohms. This branch is in multiple with load R_1 of 10 ohms and the joint resistance of these two is 6.77 ohms. The conductors, R_a and R_b, from the battery to R_1 have a resistance of ¼ ohm each or a total of ½ ohm. Thus entire resistance of the complete circuit is $6.77 + ½ = 7.27$ ohms.

By Ohm's law, the current flowing in the circuit is

$$I = \frac{\ }{R} = \frac{110}{7.27} = 15.13 \text{ amperes.}$$

The voltage drop from the battery to AB is E=IR:

$$E = 15.3 \times (\tfrac{1}{4}+\tfrac{1}{4}) = 15.13 \times \tfrac{1}{2} = 7.57 \text{ volts.}$$

The voltage at AB is the difference between the battery voltage and the drop in the line between the battery and AB, or 110−7.57=102.43 volts. This voltage will cause a current to flow through load R_2 of

$$I = \frac{E}{R} = \frac{102.43}{20+\tfrac{1}{2}+\tfrac{1}{2}} = \frac{102.43}{21} = 4.88 \text{ amperes.}$$

The voltage at CD, available for R_2 will be the voltage at AB, minus the drop in the line between AB and CD. The drop between AB and CD will be $E = IR = 4.88 \times (\tfrac{1}{2}+\tfrac{1}{2}) = 4.88$ volts, so that the voltage at CD will be 102.43−4.88=97.55 volts.

Thus the voltages at both AB and CD for R_1 and R_2 are well above the required stated minimum of 95 volts. Had they been below 95 volts, it would have been necessary to use larger conductors of lower resistance and the requirements could have been easily calculated by the use of the Working Wire Table, knowing the lengths of the conductors between the battery and points AB and CD.

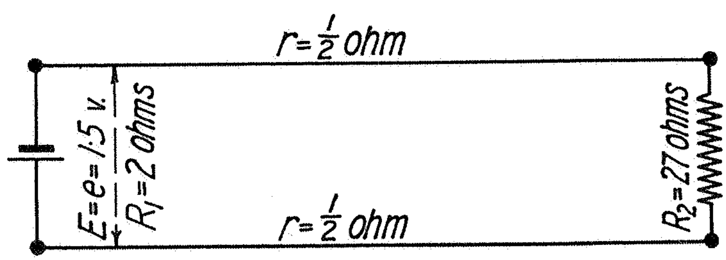

Fig. 23.
One Cell in Series with Known Resistance.

Current in a circuit of known resistance.

Referring to Fig. 23, which shows a battery in series with a known resistance:

$$I = \frac{E}{R}$$

where

- I = current in circuit, amperes
- e = open-circuit voltage of cell, 1.5 volts
- E = e = total voltage
- R_1 = internal resistance of cell, 2 ohms
- R_2 = known resistance, 27 ohms
- r = resistance of one conductor, ½ ohm
- R = total resistance of circuit
- $R = R_1 + R_2 + r + r$
- $R = 2 + 27 + \tfrac{1}{2} + \tfrac{1}{2} = 30$ ohms

Therefore,

$$I = \frac{1.5}{30} = \frac{1}{20} \text{ ampere.}$$

It will be noted that the amount of current flowing depends upon the total resistance of the circuit. This consists of the unit to be operated, the external resistance of the conductors, plus the internal resistance of the cell. The circuit is a series circuit and therefore the current is the same throughout. The voltage drop through the cell is found by the current $^1/_{20}$ ampere times the cell resistance of 2 ohms: $^1/_{20} \times 2 = 0.1$ volt. The e.m.f. of the cell at the terminals, or useful e.m.f., is therefore $1.5 - 0.1 = 1.4$ volts.

Current flowing in a circuit of known resistance with cells in series.

If a voltage higher than that of one cell is required, it can be obtained by connecting sufficient similar cells in series. For example, in Fig. 24, if one cell gives 1.5 volts, and 6 volts are required, then four cells connected in series will give 6 volts. The current output of the series battery thus formed will be equal only to the current output of one cell.

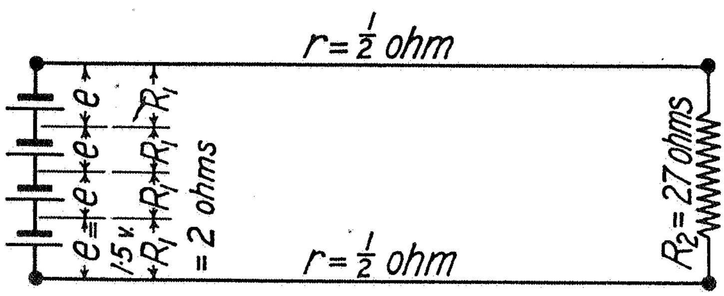

Fig. 24.
Cells in Series in a Circuit with Known Resistance.

$$I = \frac{E}{R} \text{ or } I = \frac{Ne}{NR_1 + R_2 + r + r}$$

where

I = current in circuit, amperes
e = open-circuit voltage of one cell, 1.5 volts
N = number of cells in series, (4)
$E = Ne$ = total voltage in circuit
R_1 = internal resistance of one cell, 2 ohms
R_2 = known resistance, 27 ohms
r = resistance of one conductor, ½ ohm
R = total resistance of circuit
$R = NR_1 + R_2 + r + r$
$R = (4 \times 2) + 27 + \frac{1}{2} + \frac{1}{2} = 36$ ohms

Therefore,

$$I = \frac{4 \times 1.5}{36} = \frac{6}{36} = \frac{1}{6} \text{ ampere.}$$

Current flowing in a circuit of known resistance with cells in multiple.

If two similar cells are connected in multiple, the current will equal the sum of the currents of the individual cells. The voltage of the combination will be the voltage of one cell. See Fig. 25.

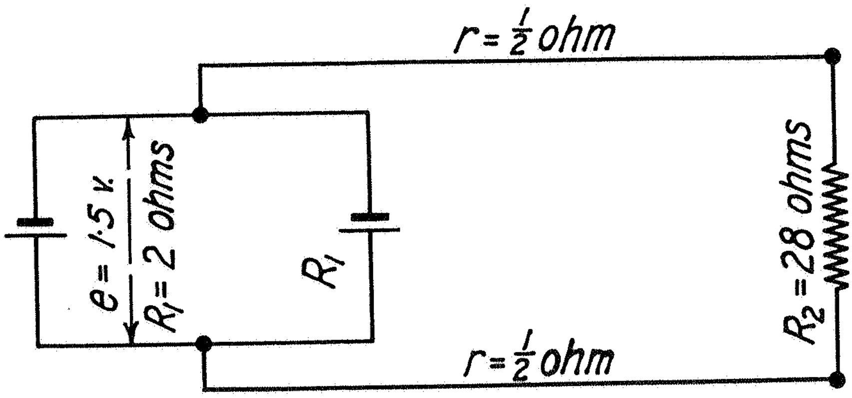

Fig. 25.
Cells in Multiple in a Circuit with Known Resistance.

$$I = \frac{E}{R} \text{ or } I = \frac{E}{\frac{R_1}{N} + R_2 + r + r}$$

where

I = current in circuit, amperes
e = open-circuit voltage of one cell, 1.5 volts
E = e = total voltage in circuit
R_1 = internal resistance of one cell, 2 ohms
R_2 = known resistance, 28 ohms
r = resistance of one conductor, ½ ohm
R = total resistance of circuit

$$R = \frac{R_1}{N} + R_2 + r + r$$

$$R = \frac{2}{2} + 28 + \tfrac{1}{2} + \tfrac{1}{2} = 30 \text{ ohms}$$

Therefore,

$$I = \frac{1.5}{30} = \frac{1}{20} \text{ ampere.}$$

Current flowing in a circuit of known resistance with cells in multiple-series.

Figure 26 illustrates a multiple-series combination consisting of four batteries in multiple, each battery consisting of four cells in series.

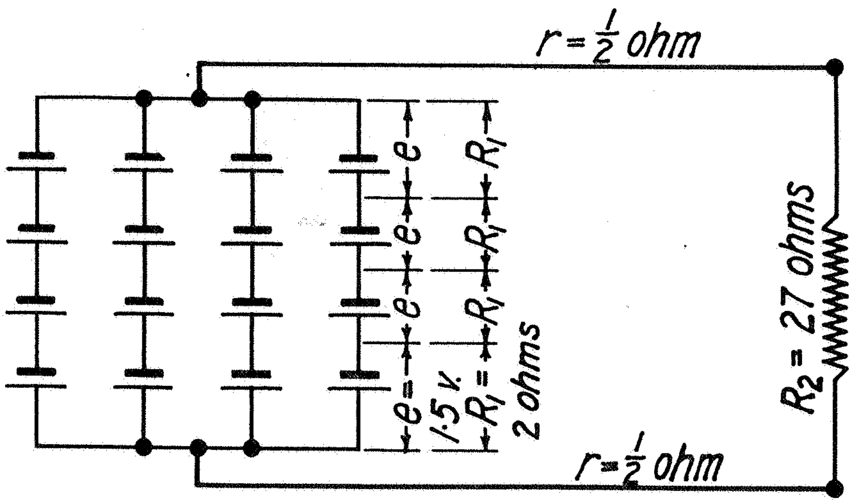

Fig. 26.
Cells in Multiple-Series in a Circuit with Known Resistance.

$$I = \frac{E}{R} \text{ or } I = \frac{Ne}{\frac{NR_1}{B} + R_2 + r + r}$$

where

I = current in circuit, amperes
e = open-circuit voltage of one cell, 1.5 volts
N = number of cells in series in one battery (4)
E = Ne = total voltage of one battery
E = total voltage since batteries are in multiple
B = number of batteries in multiple (4)
R_1 = internal resistance of one cell, 2 ohms
NR_1 = total resistance of one battery, 8 ohms
R_2 = known resistance, 27 ohms
R = total resistance of circuit

$$R = \frac{NR_1}{B} + R_2 + r + r$$

$$R = \frac{4 \times 2}{4} + 27 + \frac{1}{2} + \frac{1}{2} = 30 \text{ ohms}$$

Therefore,

$$I = \frac{4 \times 1.5}{30} = \frac{6}{30} = \frac{1}{5} \text{ ampere.}$$

Quantity of Electricity

Coulomb.

The practical unit of quantity of electricity is the coulomb. It is the quantity of electricity that flows per second past any point in a circuit when the current strength is 1 ampere. The designation for quantity of electricity is the letter Q.

Ampere-hour.

The coulomb is a very small unit of quantity; it is really an ampere-second of electricity. A larger unit, the ampere-hour, is used in practice. It is the quantity of electricity that flows per hour past any point in a circuit when the current strength is 1 ampere. The capacity of batteries is rated in ampere hours.

Capacity—Condensers

Electrical capacity.

The condenser is an electrical apparatus used for storing electricity. The original condenser was the Leyden jar, as previously explained. It was found to retain charges of electricity. At the present time condensers are made in different forms, but consist of two or more metal plates, separated by a narrow gap of air or insulating material called the dielectric.

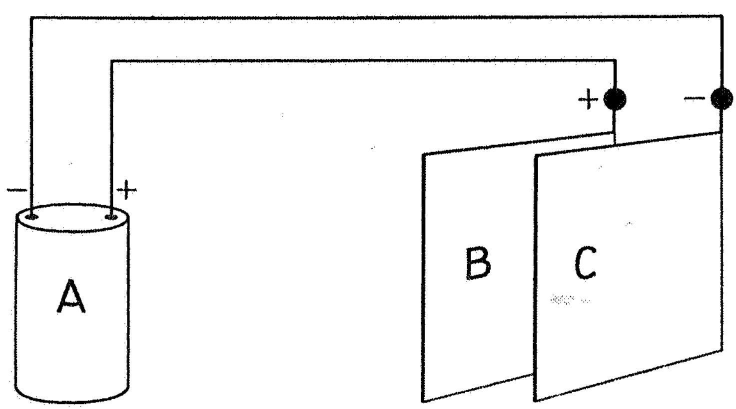

Fig. 27.
Simple Condenser.

Some condensers consist of pieces of tinfoil with oiled paper between, and another type which is very familiar is the variable condenser, used in radios, which consists of a number of plates that move between a number of other plates using the air as a dielectric.

In Fig. 27, the closing of the circuit of the cell A charges plates B and C, and the voltage across B and C becomes equal to the voltage of the cell, B receiving a positive charge and C a negative charge. The greater the area of the plates and the nearer they can be placed to each other without causing a spark to jump across, the greater the quantity of electricity the plates will hold; that is, the capacity will be increased. When charged, the plates may be disconnected from the battery, and will retain their charge, if insulated. The condenser is discharged by connecting its plates together, thus reducing them to the same potential.

Dielectric strength.

The dielectric strength of any insulating substance can be tested by the condenser. A thin layer of the material is placed between the two conducting plates, and a voltage built up on the plates until the material breaks down and a spark burns a hole through it. The difference of potential just preceding that which punctures or breaks down the insulation determines the value of the dielectric strength of the insulating material.

Unit of capacity.

The capacity of a condenser is measured by the quantity of electricity with which it must be charged in order to raise its electric potential from zero to 1 volt. The practical unit of capacity is the farad. A condenser has a capacity of 1 farad when 1 coulomb is necessary to raise its potential from zero to 1 volt. The farad being inconveniently large, the microfarad (mf.), which is one one-millionth part of a farad, is generally used in practical work. The designation for capacity is the letter C.

Electro-Dynamics

Electricity and mechanical motion; dynamos and motors.

Reviewing magnetism, static electricity, and the electric current, it is found that artificial magnets have been made from natural magnets, static electricity has induced electric charges on other bodies and produced sparks when discharging between bodies; the electric current has caused chemical changes, and has converted a coil of wire into a magnet whose strength is greatly increased by a core of soft iron. When it was discovered that cutting magnetic lines of force with a conductor produced an electromotive force, loops or coils of wire were arranged to revolve around an axis between two magnetic poles, so as to cut magnetic lines of force and generate an electromotive force which could be impressed upon an electric circuit and made to do work. If the loops or coils were rotated continuously by external mechanical force, it was possible to collect the e.m.f. generated either as alternating or direct voltage, depending upon the arrangement of the collecting apparatus.

Direct current has a unidirectional voltage, and the current flows constantly in one direction, positive to negative. Alternating current has a voltage with a periodic fluctuation; it starts at zero, rises to maximum value in one direction, falls to zero, rises to maximum value in the other direction, and again falls to zero, to start the entire process over again. The period during which it flows in one direction is called an alternation, while the entire period made up of one positive and a succeeding negative alternation is called a cycle.

The electric machine with the revolving loops or coils described above, which transforms the mechanical energy used to revolve these coils into electrical energy is called the dynamo or generator. When the operation was reversed, and a current sent through the coils or loops, it was found that they revolved, thus transforming electrical energy into mechanical energy. This latter machine is called the electric motor.

Motion had been produced previously by magnetic attraction of the armature of a magnet, and the movement of the iron core of a solenoid. In later years, magnets have been made to pick up tons of magnetic substances, and solenoids have been used in signaling to operate semaphore signals and train stops of the trip type.

Energy and power.

The energy or work of the electric current from the generator is converted into light energy, heat energy, chemical energy, and mechanical energy. Power is the rate of changing energy from one form to another, or the time-rate of doing work.

Unit of power.

It has been found by experiment that the power in any part of an electrical circuit is proportional to the product of the electromotive force at its terminals and the amount of current flowing.

The amount of power generated by an electromotive force of 1 volt causing a current of 1 ampere to flow is the unit quantity of power and is called the watt. The kilowatt (kw.) is a larger unit of power, equal to 1000 watts. Seven hundred and forty-six watts correspond to 1 horsepower. The designation for power is the letter P.

Unit of energy.

Since, as previously brought out, power is the rate of transformation of energy from one form to another, it follows that the amount of energy transformed is equal to the product of power by time of transformation. When the power, or rate at which work is being done, is 1 watt, then the work done in 1 second is 1 watt-second, and is called 1 joule. The joule is the unit of energy. The watt-hour or 3600 joules is often used, while a still larger unit is the kilowatt hour. The joule is represented by the letter W.

Unit of heat.

In the metric system the unit of heat is the gram-calorie, which is the amount of heat necessary to raise the temperature of 1 gram of water through 1 degree Centigrade (from 14.5 to 15.5 degrees Centigrade).

In the British system the unit of heat is the British thermal unit (B.t.u.) which is the amount of heat necessary to raise the temperature of 1 pound of water through 1 degree Fahrenheit.

Conversion Table of Power, Energy and Heat Units

Unit	Mechanical	Electrical	Heat
1 hp.	33,000 ft.-lbs./min. 550 ft.-lbs./sec.	746 watts 746 joules/sec. 0.746 kw.	2546 B.t.u./hr. 42.44 B.t.u./min. 0.707 B.t.u./sec.
1 hp.-hr.	1,980,000 ft.-lbs.	0.746 kw.-hr.	2546 B.t.u.
1 ft.-lb.	—	1.356 joules	0.001286 B.t.u. 0.3242 gram-calorie
1 joule	0.7375 ft.-lb.	1 watt-sec.	0.0009488 B.t.u. 0.2390 gram-calorie
1 watt	0.001341 hp. 0.7375 ft.-lb./sec.	1 joule/sec.	3.415 B.t.u./hr.
1 kw.	1.341 hp. 2,655,000 ft.-lbs./hr. 44,250 ft.-lbs./min. 737.5 ft.-lbs./sec.	1000 watts	3415 B.t.u./hr. 56.92 B.t.u./min. 0.948 B.t.u./sec. 238.9 gram-calories/sec.
1 kw.-hr.	2,655,000 ft.-lbs.	3,600,000 joules	3415 B.t.u. 860,400 gram-calories
1 B.t.u.	777.5 ft. lbs. 0.0003927 hp.-hr.	1054 watt-sec. 1054 joules 0.0002932 kw.-hr.	252.2 gram-calories 0.2522 kilogram-calories
1 gram-calorie	—	4.184 joules	0.003968 B.t.u.
1 kilogram-calorie	—	—	1000 gram-calories 3.968 B.t.u.

Power formulae.

$$I=\frac{E}{R} \qquad E=IR \qquad R=\frac{E}{I} \qquad P=EI$$

$$I=\frac{P}{E} \qquad P=\frac{E^2}{R} \qquad P=I^2R$$

$$hp.=\frac{P}{746} \qquad P=hp.\times 746$$

Energy distribution.

Notice that the number of watts may be found either by multiplying the voltage E by the current I or by multiplying the resistance R by the current squared.

$P=EI$, $E=IR$, therefore $P=I^2R$. I^2R is the power in watts required to force the current through any circuit, as all circuits have some resistance. This power is transformed into heat.

Power loss from resistance.

An electric current flowing through a conductor dissipates energy in and heats the conductor. This effect is like friction, in that electrical energy is converted to heat energy and lost. The voltage necessary to cause the current to flow is like the force necessary to move a body against the resistance of friction, and is called the resistance voltage. It has been proven that for direct current the resistance voltage of a solid or liquid conductor depends only upon the current and upon the dimensions, and upon the material and physical state of the conductor, and has no relation to the properties of external conductors, surrounding insulators, nor other external circumstances. The power lost (P) in heat is the product of the resistance voltage (IR) and the current, or,

$$P = E \times I$$

In the preceding paragraph it was also noted that the heat loss can be written $P = I^2R$. The power lost in a wire as heat due to its resistance is proportional to the square of the current. The heat loss is usually called the I^2R ("I" square "R" loss).

Electrical distributing systems.

Figure 28 shows an electrical distributing system with a generator (G) in a power house sending power through a transmission line to a factory where there is a load of a motor (M), a light and a heater, illustrating the conversion of electrical energy into mechanical energy, light energy and heat energy. A storage battery on charge would represent a conversion of electrical energy to chemical energy.

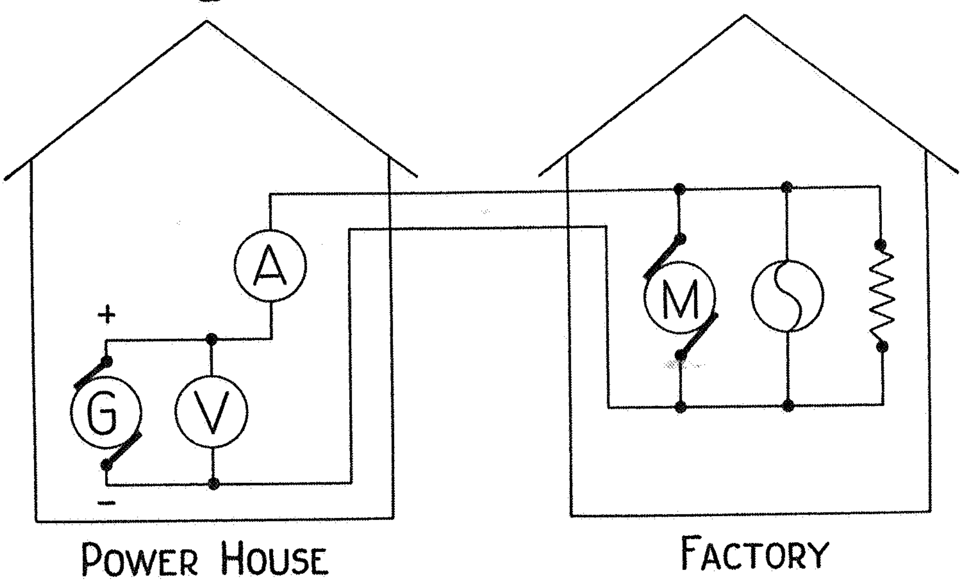

Fig. 28.
Generating and Distributing System.

In the power house the voltmeter (V) indicates 100 volts between the positive and negative conductors, and the ammeter (A) indicates an output of 10 amperes through the conductors.

(*a*) *Power generated.*

The number of watts produced is obtained by using the formula

$$P = EI, \text{ or } P = 100 \times 10 = 1000 \text{ watts, or 1 kw.}$$

(*b*) ***Drop of voltage in line.***

The drop of voltage is found by using the formula E = IR. The resistance of the line (*i.e.,* both conductors) between power house and factory is 2 ohms.

The drop in voltage between power house and factory is 10 $\times$ 2 = 20 volts, therefore the voltage at the factory is 100 − 20 = 80 volts.

(*c*) ***Loss of power as heat in transmission line.***

The loss of energy as heat in the transmission line is obtained by using the following formula:

$$P = I^2R, \text{ or } P = 10 \times 10 \times 2 = 200 \text{ watts.}$$

Therefore, the power consumed, in carrying the current from the power house to the factory through the combined resistances of the positive and negative conductors, by being converted into heat and dissipated, is 200 watts. If the conductor is not large enough to carry the current, that is, if its resistance is high and it has, consequently, a high I^2R loss, it may be heated enough to burn the insulation of the conductor.

In order that there may not be any over-heating of the conductor, and that whatever heat is produced may be radiated safely in the insulation of the conductors, the amount of current is limited for certain sizes of conductor with certain insulations as shown in the following table:

Allowable Continuous Current-Carrying Capacities of Copper Wires and Cables of 98 Per Cent Conductivity
(National Electrical Code—1935)

	Carrying Capacity in Amperes	
Size of wire	Rubber insulation	Other insulation and bare conductors
1,000,000 c.m.	650	1000
500,000 c.m.	400	600
0000 A.W.G.	225	325
00	150	225
0	125	200
1	100	150
2	90	125
3	80	100
4	70	90
5	55	80
6	50	70
8	35	50
10	25	35
12	20	30
14	15	20
16	6	10
18	3	6

(For aluminum wires with the same insulation, take 84 per cent of the above values.)

Power consumed by lamps.

When a lamp is rated as a 50-watt lamp for 110 volts, it means that when burning at 110 volts it consumes 50 watts. The current used is $I=\frac{P}{E}$ or $\frac{50}{110}=0.455$ ampere. The resistance of the lamp at 110 volts is $R=\frac{E}{I}$ or $\frac{110}{0.455}=242$ ohms. If the resistance of the lamp remained constant, at 100 volts the watts consumed would be $P=\frac{E^2}{R}=\frac{100 \times 100}{242}=41.4$ watts.

Actually, the resistance of tungsten lamps decreases with a reduction in voltage so the actual watts at 100 volts for the above example would be somewhat higher than 41.4 watts.

The information contained herein does not represent the entire subject covering the fundamental theory of direct current but it does represent that portion which, if clearly understood, will enable a person to form a practical idea of the application to signaling of the laws governing direct current phenomena.

American Railway Signaling Principles and Practices

QUESTIONS ON

CHAPTER XXII

Manual and Controlled Manual Block Systems
and
Fundamental Theory of Direct Current

QUESTIONS

MANUAL AND CONTROLLED MANUAL BLOCK SYSTEMS

1. How does the Standard Code of the American Railway Association define:
   (a) Block System?
   (b) Manual Block System?
   (c) Controlled Manual Block System?
   (d) Block Station?
   (e) Block?
   (f) Fixed Signal?
   (g) Block Signal?

General.

2. What is the purpose of block systems?

3. Prior to the adoption of the block system, what was the means used to avoid collisions?

4. Where is the time interval still in use?

5. How many general types of block systems are in use and how are they designated?

Rules.

6. Do block signals supersede the superiority of trains or dispense with the use or the observance of other signals whenever and wherever they may be required?

7. What do controlled manual block signals govern, and do they dispense with the use or the observance of other signals whenever and wherever they may be required?

8. When a block station is open at an irregular hour, how must trains be notified?

9. What special precautions, with respect to calling attention to trains approaching such block station, must be taken?

SIGNALMEN

10 In what position must signals be kept?

11. How must appliances be operated?
    (a) If any irregularity affecting their operation is detected, what action must be taken?

12. What must signalmen observe in regard to the indication of the signals and levers?

13. What is required with respect to alterations or additions to the apparatus?

14. What record must be kept at each block station?

COMMUNICATING CODE.

15. What do the following numbers, used in the communicating code, designate: 1, 13, 17, 2, 3, 36, 4, 46, 5, 56, 7, 8 and 9?

(a) If the block is clear, how is it to be answered?

(b) If the block is not clear, how is it to be answered?

(c) When two or more tracks are used in the same direction, what must signalmen in using the code also specify?

16. Under Rule 317-A, to admit a train to a block, what must the signalman do?

(a) What must the signalman receiving the signal do if the block is clear?

(b) If the block is not clear, how must the signalman reply?

(c) What must the signalman at the entrance of the block then do?

(d) Except how may a train be admitted to a block that is not clear?

17. Under Rule 317-B, to admit a train to a block, what must a signalman do?

(a) What must the signalman receiving the signal do if the block is clear?

(b) If the block is not clear, how must the signalman reply?

(c) What must the signalman at the entrance of the block then do?

(d) Under what provision may a train be admitted to a block which is occupied by an opposing train or by a passenger train?

(e) What is the procedure to permit a train to follow a train other than a passenger train into a block?

18. May additions be made to the communicating code?

(a) When may the code be used without the numerals?

19. What movements are protected under Rule 317-A?

20. What movements are protected under Rule 317-B?

21. Under Rule 318-A, how is a train admitted to a block?

(a) When may a train be admitted to a block that is not clear?

22. Under Rule 318-B, how is a train admitted to a block?

(a) Except how may a train be admitted to a block which is occupied by a passenger train under Rule 318-B?

(b) What train may be followed by another train under Rule 318-B?

23. Under Rule 319, what is the procedure when a train enters a block?

24. When must signalmen not ask for the block?

25. Why must observation, as far as practicable, be made by signalmen of all passing trains?

26. What movements are protected under Rule 318-A?

27. What movements are protected under Rule 318-B?

28. How may Rules 317-A, 317-B, 318-A and 318-B be modified?

29. How are the blanks to be filled in Rules 317-A, 317-B, 318-A, 318-B and 319?

30. Should a train pass a block station with any indication of conditions endangering the train, or a train on another track, what action must immediately be taken by signalman?

31. Should a train without markers pass a block station, what action must be taken by signalman?

32. Should a train pass a block station in two or more parts, what action must signalman take?

(a) Having received a Train-parted signal, what action must signalman take?

(b) Should a train in either direction be stopped, when may it be permitted to proceed?

33. What action must a signalman, informed of any obstruction in a block, take?

34. When a train takes a siding or otherwise clears the main track, what must be known by signalman before giving 2 or displaying a Clear-signal for that block?

(a) What action must be taken by the signalman before permitting a train to re-enter the block?

35. To permit a train to cross over or return, unless otherwise provided, what action must be taken by signalman?

(a) Until the block is clear, under what conditions only must a train be admitted in the direction of the cross-over switches?

(b) How must cross-over movements be recorded?

36. When coupled trains are separated, how must signalman regard each portion of the train?

37. When necessary to stop a train for which a Clear or Permissive signal has been displayed and accepted, what must be done by signalman in addition to displaying the Stop-signal?

38. What signal must be displayed by signalman having train orders for a train?

(a) How may a train stopped for train orders be permitted to proceed?

39. When from the failure of block signal apparatus the block signal cannot be changed from the most restrictive indication, a signalman having information from signalman at the next block station in advance that the block is clear, how may he admit a train to the block?

(a) If the block is occupied by a train, other than an opposing train or a passenger train, how may signalman admit a following train?

40. When from the failure of the block signal apparatus the block signal cannot be changed from its most restrictive indication, or when a signalman is unable to communicate with the next block station in advance, how may he admit a train to the block?

41. What must be done with operating levers when a track, switch or signal is undergoing repairs or when a track is obstructed?

42. When, from any cause, a signalman is unable to communicate with the next block station in advance, what action must be taken?

(a) Should no cause for detaining a train be known, how may it be permitted to proceed?

43. When a signalman is unable to communicate with the next block station in advance, or if from the failure of the block signal apparatus the block signal cannot be changed from the normal indication, what action must he take?

(a) If unable to communicate with the ...., after any train for which 2 or 13 had been given to the next block station in advance has cleared the block, how will trains be permitted to proceed?

44. May hand signals be used when the proper indication can be displayed by the block signals?

(a) When hand signals are necessary, what precaution must be used when giving them?

45. To what trains do block signals for a track apply?

(a) What is used by signalmen for blocking trains moving against the current of traffic?

46. For what apparatus are signalmen responsible?

47. What are the requirements about placing lights in block stations?

48. Rule C-331 is for the operation on what tracks?

49. Rule C-333 is for the operation on what track?

50. What does hand signaling include the use of?

51. How may a railroad fill in the blank in Rule 335?

52. If a train overruns a Stop-signal, to whom must the fact be reported?

53. If a train disregards a Stop-signal, to whom must the fact be reported?

54. To open a block station, what procedure is taken?

(a) When trains, which were in the extended block when the block station was opened and which had passed his block station before it was opened, clear the block in advance, to whom must he repeat the record?

55. Upon whose authority only must a block station be closed?

56. May a block station be closed before the block in each direction is clear of all trains?

(a) To close a block station, what action must signalman take?

(b) When the block station is closed what must be done in regard to signals, lights, block wires, and, when necessary, circuits?

57. When a block station is open at an irregular hour, what signals are required, and to what extent?

(a) What special precautions must signalmen take when trains approach the block station?

58. Who must signalmen not permit to enter the block station?

ENGINEMEN AND TRAINMEN

59. To what trains do block signals for a track apply?

(a) What will be used for blocking trains against the current of traffic?

60. Under *M*-362, when only may trains pass a Stop-signal?

61. Under *C*-362, when only may trains pass a Stop-signal?

(a) On single track, upon what authority may trains receiving Clearance Form B proceed and what may they expect to find within the block?

62. Is it permissible for trains to proceed on hand signals against block signals?

63. Unless otherwise directed, when two or more trains have been coupled and so move past any block station, where only must they be separated and who must be notified?

64. How may each railroad fill in the blank in Rule 361?

65. When a train takes a siding or otherwise clears the main track what permission is necessary before again entering the block or fouling the main track?

(a) A train having passed beyond the limits of a block, what permission is necessary before backing into that block?

66. Unless otherwise provided, what permission is necessary before crossing over or returning?

67. When approaching a block station, what signal must be given by engineman of a train which has parted?

68. How must an engineman, receiving a Train-parted signal from a signalman, answer?

69. When a parted train is recoupled, who must be notified?

70. When there is an obstruction between block stations, to whom must notice be given?

71. When a train is stopped by a home or block signal what action must be taken and by whom?

72. By whom and to whom must any unusual detention at block stations be reported?

73. When only must a block station be considered as closed?

Manual Block

74. What is manual block?

Double track.

75. What does Fig. 1 illustrate?

76. When a train passes block station A, as illustrated in Fig. 1, to whom does signalman at A report?

77. What action does signalman at B take when getting the report of train passing block station A?

78. When train enters block at block station B what action does signalman at block station B take?

79. When does signalman give record of train to block station A?

80. What record is kept of the information given block station A?

81. What information would the block sheet at block station B then show?

82. Should it be necessary for the train to be held at block station B for any reason, what record would be made?

83. If the train is not held at the block station, what record is made and where is it shown?

84. What does Fig. 2 show?

85. How is provision made for fast moving trains to pass slower moving trains?

86. A freight train traveling from A toward D and has passed C about the time a passenger train passes A and the freight train will not have time to get to D before the passenger train reaches C, what is the procedure?

87. If one freight train is passing another freight train, when may the slower train follow from the siding?

88. Are arrangements in effect relative to method to be followed should means of communication fail between an outlying point and the signalman?

89. What is one method prescribed if means of communication fails?

Single track.

90. What does Fig. 3 illustrate?

91. How is the frequency of sidings determined?

92. Assume two trains of the same class traveling toward each other from block stations A and D, which train is superior by direction, and when is it necessary for the inferior train to clear on a siding?

93. In Fig. 3, what block has signalman at block station A obtained, in accordance with what rule, and for what movement is a clear block signal displayed?

94. What block is obtained by signalman at D so that the inferior train passes block station D with a clear signal?

95. As the superior train approaches block station B, what block is obtained before giving a clear block signal at B?

96. In what position are the signals at block station C kept with both trains approaching?

97. What is the procedure of the inferior train approaching station D with reference to taking siding for the superior train also approaching?

98. After the inferior train has taken the siding, what is the procedure of signalmen at block stations D and C in handling the superior train?

99. On arriving at the other end of siding, what is the procedure of the conductor of the inferior train?

100. What action is taken by signalman at block station C before permitting the inferior train to proceed toward B?

101. After receiving permission for block from signalman at block station B, what authority and advice is given the train leaving the siding?

102. What is the procedure of signalman at B so that he can display proper signal for this inferior train?

103. What is the restriction in regard to passenger trains between block stations?

104. As a general proposition, how do a large number of railroads permit freight trains to use the block moving in the same direction and what is this blocking known as?

105. Where only one train is permitted in either direction in the same block at the same time, what blocking is this known as?

106. Describe some of the arrangements of sidings in effect on different railroads.

107. What is the advantage of lap sidings as shown at block station B, Fig. 3?

Controlled Manual Block

108. Under the system of controlled manual block, how are the signals operated and controlled?

109. In addition to the operators communicating with each other to obtain the use of the block, what are the other requirements?

110. With Controlled Manual Block Signal Rules in effect, how may trains be run?

111. What circuits are shown in Fig. 4 and how would circuits for multiple-track operated under Controlled Manual Block Rules compare?

112. At block station A, what movement does signal 14 govern and what movement does signal 10 at block station B govern?

113. What action is necessary by the signalmen before either signal can be cleared?

114. What device and in what position is it that permits train movements toward and from that particular block station?

115. In what position do the circuits, as shown in Fig. 4, have the traffic lever at each block station?

116. What type machine is shown at station A and at station B?

117. Is traffic lever FMK, at block station A, part of the interlocking?

118. What is the traffic lever known as and in what figure is it shown?

119. What position of the lever is the B or indicating position?

120. Is the traffic lever, shown at block station B, part of the interlocking and what are its positions?

121. At block station A, what type locking is between traffic lever FMK and signal lever 14?

122. At block station B what type locking is between traffic lever 11 and signal lever 10?

123. Why is signal 14 at A only a two-position while signal 10 at B is three-position?

124. Assume a train movement is to be made from A to B, what is the procedure of signalmen at A and B?

125. Describe the circuit that releases FMK at A.

126. Describe the circuit that lights lamp ZE.

127. Describe the circuit that is completed with relay Z at A energized.

128. How does the circuit just described effect lever FMK?

129. Describe the circuit that energizes the coils of electric lock FL on signal lever 14.

130. What effect does the releasing of electric lock FL have on lever 14?

131. Describe the circuit that causes signal 14 to display a clear signal.

132. With signal 14 displaying a proceed indication, what would be the effect upon traffic lever 11 at B and what would prevent signal lever 10 from being moved to the right?

133. What is necessary before traffic can be set up from B to A?

134. Describe the circuit that allows the return of signal lever 14 to the normal position.

135. Why is a release circuit provided?

136. Describe the release circuit.

137. Upon what does the time, for which time release 14TE is set, depend?

138. Describe the circuit that permits FMK being placed in the L position.

139. For a train movement from B to A, what is the procedure that permits signalman at B to reverse traffic lever 11?

140. What effect does lever of instrument FMK at A in the L position have on signal lever 14?

141. Why is there a short track circuit immediately in advance of signal 10 at B?

142. If sidings or tracks on which trains may clear the main track are located between block stations, what is it necessary to provide?

143. What does Fig. 6 illustrate and what are the circuits arranged to allow?

144. In the installation shown in Fig. 6, what kind of circuit controllers are used and how do their locking segments compare with those shown in Fig. 4?

145. Assume a movement is to be made from A to B, what action is taken by the signalmen at A and B?

146. Describe the circuit for instrument LFMK.

147. With the circuit for instrument LFMK complete, how does it effect lever LFMK at A?

148. How does this circuit compare with the releasing circuit in Fig. 4, and what additional assurance does it provide?

149. With lever LFMK at block station A in the R position, describe the circuit for instrument FMK.

150. As the lever of instrument LFMK was moved to the R position, how did it effect instrument FMK?

151. Describe the circuit that controls the lock magnet FL on lever 14.

152. What effect does the energization of lock magnet FL have on signal lever 14?

153. Assume a movement from eastward siding C to block station B instead of from A to B, how would the signalman at A proceed?

154. Describe the circuit that energizes coils of electric lock "C"WL.

155. How does the energization of electric lock "C"WL effect siding C?

156. What indication can now be displayed at signal 14 if necessary?

157. How does the short track circuit in advance of this signal compare with that shown in Fig. 4?

158. After a movement has been started from block station A to B, what is necessary before the signalman at A can release the instruments at B, for a move from B to A?

159. How do the circuits for this move compare with those described in unlocking A from B?

160. Assume a train is moving from block station A to B and it is necessary for this train to enter siding at switch D, what must first be done?

161. What effect will the train on track circuit 07T have on track relay 07TR?

162. After the conductor of this train has called the signalman at block station B to unlock the siding switch, what would be the signalman's procedure?

163. Describe the circuit that will be completed with lever "D" L in the L position.

164. How is the circuit, that will energize coils of electric lock "D"WL, completed?

165. How does the energization of electric lock "D"WL effect the unlocking of switch D?

166. After train has reported clear of the main track, switch closed and locked, what is the procedure of signalman at B?

167. Should it be necessary to make a movement from siding through switch D to block station A, what must signalman at B first establish?

168. Describe the procedure and circuit that would energize the coils of relay DWR.

169. Describe the circuit for electric lock "D"WL.

170. What effect will the energization of electric lock "D"WL have upon switch D and what effect will a train between stations B and A have on traffic?

171. Why are the complete circuits for control of operating units at block stations A and B not shown?

172. Should there be additional main tracks between block stations A and B, under Controlled Manual Block System Rules as shown in Fig. 6, how would they be arranged and controlled?

173. How do the various schemes of circuits, other than those shown in this chapter, in use between block stations for Controlled Manual Block System Rules, compare with those shown and what are the main requisites?

174. How do certain installations that are in service in which Controlled Manual Block System Rules are in effect for opposing movements and Automatic Block System Rules for following movements compare with those just described?

FUNDAMENTAL THEORY OF DIRECT CURRENT

Elements

Nature of electricity.

175. Give a definition of the nature of electricity.

176. How is it known that electricity is a form of energy? Give an example.

177. Can heat energy be transformed into electrical energy? Give an example.

178. Give an example of the transformation of electrical energy into chemical energy, and of the reverse process.

179. What great advantage has electricity over other forms of energy?

Static electricity.

180. What name is applied to electric charges when at rest on bodies?

(a) *Attraction and repulsion.*

181. When were many experiments made with static electricity, and what was found out about its nature?

182. Of what, according to modern scientific theory, is all matter composed?

183. How do the number of protons and electrons compare in a body which is not electrically charged?

184. When a body has more electrons than protons how is it said to be charged?

185. When a body has fewer electrons than protons how is it said to be charged?

186. Which kind of charges repel each other, and which attract?

187. What conditions affect the force of attraction or repulsion between charged bodies?

188. On what part of a body is the electric charge found?

(b) Electrostatic induction.

189. What name is given to materials which offer high resistance to the flow of electricity; to those which offer but little resistance?

190. Does an insulating body hold its charge longer than a conducting body?

191. Under what conditions will a positive and a negative charge neutralize each other?

192. When a charged body is placed near a neutral body, what will be the effect and what is it called?

193. What is the similarity between a charged body and a magnet in their action on neutral bodies?

(c) The Leyden jar; condensers.

194. Before the invention of batteries and electromagnetic generating machines, what was developed to produce electric charges by friction?

195. During this period what was developed to receive and store electrical charges and how was it constructed?

196. What would be the effect of moisture on a Leyden jar?

197. How is the Leyden jar charged?

198. When does the inside tinfoil become positively charged and the outside tinfoil become negatively charged?

199. What determines the amount of electric charge which a Leyden jar will store?

200. If a Leyden jar is overcharged what is the effect on the glass wall between the tinfoil coatings and what is the likely result of overcharging?

201. Why is the Leyden jar not so convenient as the modern condensers now in use?

(d) Lightning.

202. How does lightning and the spark that travels from one coating to the other of a Leyden jar compare?

Dynamic electricity.

203. When is electricity known as dynamic electricity?

204. What apparatus produced the first known sustained electric current; who discovered it, and when? Of what does it consist?

205. How was the current produced?

206. What is considered to be the forerunner of present-day batteries?

207. How was it shown that Voltaic or dynamic electricity is the same as static electricity?

Difference of potential—voltage.

208. What is necessary to cause an electric current to flow through a conducting body?

209. What term is applied to the point of higher potential; the point of lower potential?

210. What is potential difference?

211. How is electromotive force measured?

212. What is the voltage of an ordinary caustic soda cell; of a dry cell?

213. What is the usual voltage of the third-rail of an electric propulsion railroad?

214. On electric propulsion railroads using overhead catenary, what is the potential difference between catenary and rails when using alternating current? When using direct current?

215. On a third-rail or catenary direct current system, which is the positive and which is the negative conductor?

Conductors and insulators.

216. What is an electric conductor?

217. When is a material termed a conductor? An insulator?

218. What unit is used to measure resistance?

219. What is the approximate resistance of 1000 feet of No. 10 A.W.G. copper wire?

Conductors.

220. What is the approximate conductivity of the following conductors, taking silver as a standard of 100 per cent conductivity:

Copper
Gold
Aluminum
Telephonic bronze
Copper, 10 per cent bronze
Zinc
Brass, 30 per cent zinc
Phosphor tin
Platinum
Soft iron
Swedish iron
Pure tin
Aluminum bronze
Steel
Copper, 10 per cent nickel
Lead
Bronze, 20 per cent tin
Phosphor bronze, 10 per cent tin
Antimony
Mercury
Charcoal
Acid solutions
Saline solutions
Water
Human body

221. Name some partial conductors or insulators.

Insulators.

222. Name some typical insulators.

223. Upon what do insulating properties depend to a great extent?

224. What is the effect on the insulating properties of some materials when dry and when wet?

225. What other condition greatly affects the insulating property of materials?

Batteries

226. In which chapter are batteries fully described?

Electrolysis

227. Describe electrolysis and state how it compares with the action in a primary and in a storage battery.

228. How is the principle of electrolysis applied commercially?

229. How may water mains, gas mains, lead coverings of cables, or any underground metal line become corroded by electrolysis?

Magnetism

Nature of magnetism.

230. What property makes a substance a magnet?

Artificial magnets.

231. How is an artificial magnet made?

232. Why are artificial magnets used instead of natural magnets?

233. How are the north and south poles of a magnet determined?

234. Where is the attractive power of a magnet greatest and where does its attractive power cease?

235. If a magnet be broken into several pieces, what is the effect on the magnetic attraction of each piece?

Attraction and repulsion of magnets.

236. Which poles of magnets attract each other and which repel?

Magnetic field.

237. Of what does a magnetic field consist and how may it be made apparent?

238. What general type of magnets are shown in Figs. 8 and 9?

Flux.

239. What are lines of force in any stated area called and what is known as field intensity, or flux density?

240. What does the magnetic flux possess along its own direction and what does it possess at right angles to the direction of the lines of force?

241. What is the resultant effect on the lines of flux?

Magnetic substances.

242. When a body is placed within a magnetic field and becomes an artificial magnet, what is it called?

243. If it retains the magnetic properties when removed from the field, what is it called?

244. What is the magnetism called that remains in a magnetic substance after it is removed from the magnetic field?

245. What will cause a permanent magnet to lose its magnetism?

Relation between the electric current and the magnet.

246. What is the relation between electric current and magnetism? When and how was this discovered?

247. How is a magnetic needle affected when a wire carrying a current is placed near and parallel to it?

248. Upon what does the amount of the deflection of the needle depend?

249. In what direction does the current flow in the wire running north and south in the circuit shown in Fig. 10?

250. How will a magnetic needle beneath the wire have its north-seeking pole deflected, and under the same conditions of current flow what will be the effect with the needle placed above the wire?

251. What would reverse the deflection of the needle in the two cases?

Solenoid.

252. What is a coil of wire wound in the form of a helix, or tube, as shown in Fig. 11, called?

253. What results when a current flows through a solenoid?

254. Upon what does the polarity of the solenoid depend?

255. What effect does a reverse direction of current have on its polarity?

256. How is the magnetic property affected when the flow of current is stopped?

257. How is the polarity determined?

258. Where is the magnetic field of the solenoid the strongest?

259. If a plunger of soft iron be partially inserted in a solenoid, which is carrying a current, what will be the effect?

260. What work can the solenoid therefore be used to do?

Electromagnets.

261. Describe an electromagnet.

262. What makes the iron core a magnet?

263. Of what shape are electromagnets, generally?

264. What is the essential feature in regard to the direction of winding of a horseshoe-shaped electromagnet?

265. How does the polarity compare at the ends of horseshoe-shaped electromagnets?

266. Where are electromagnets used extensively?

Electromagnetic induction.

267. When an electrical conductor, such as a wire, is moved across a magnetic field, so as to cut magnetic lines of force, what takes place in the conductor, and if the moving conductor is part of a closed circuit, what will result?

268. To what is the strength of the e.m.f. so generated proportional?

269. Is it known why an e.m.f. should be generated when a conductor cuts across a magnetic field?

270. If the conductor is formed into a loop and is held stationary in the magnetic field at an angle to the magnetic lines of force and the flux density of the magnetic field is varied, to what will the e.m.f. generated in the loop be proportional and when will the maximum e.m.f. be generated?

271. What will be the effect of a sudden removal of the magnetic field?

272. By rotating the loop in the magnetic field, as shown in Fig. 14, what will be the effect on the number of magnetic lines of force threading the loop, and what will be generated in the loop? Of what is this the principle?

273. Why will a coil carrying a current on being inserted into another coil produce an e.m.f. in that coil, and to what does it correspond?

274. Where is detailed information on this subject given?

Induction coils.

275. If two coils are in independent electric circuits and one coil is placed inside of the other, and an increasing and decreasing current is caused to flow in, say, the inner coil, what will result?

276. How will these magnetic lines of force affect the outer coil?

277. To what will the induced e.m.f. be proportional?

278. If the outer circuit is closed, what will be the result?

279. How will the direction of the induced e.m.f. compare with the e.m.f. of the inner coil?

280. Will electromotive force be induced when the flow of current in the inner coil is constant?

281. Ordinarily in direct current work, when will the condition of a changing electromagnetic field occur?

282. What is the combination of two such coils, with a device to continuously interrupt the current in the inner coil called, and why is it used?

283. Of what is the action of the induction coil the basis?

284. Which is termed the primary and which the secondary coil?

285. Why was the inner coil chosen as the primary, and would the action be any different if the outer coil had been taken as primary and the inner coil as secondary?

Self-induction and mutual induction.

286. When will the electromagnetic field, surrounding a coil, due to a current flowing in the coil, increase and decrease?

287. What effect is produced in the coil as the current changes in it, and why?

288. When does the counter e.m.f. oppose and when does it assist the e.m.f. which causes the current to flow through the coil?

289. When a counter e.m.f. is produced in a coil due to a changing current in the coil, what is the effect termed?

Unit of self-inductance.

290. When current is caused to change uniformly at the rate of 1 ampere per second and the counter-electromotive force is 1 volt, what is the coefficient of self-inductance of the coil said to be?

291. What is the henry and how is it designated?

292. If two coils are adjacent but in independent electric circuits and the lines of force of the electromagnetic field, due to a changing current in one coil, cut the turns of the adjacent coil, what will result in the adjacent coil?

293. How will the direction of the induced e.m.f. in the adjacent coil compare with the direction of the e.m.f. in the field producing coil when the current is increasing and decreasing?

Unit of mutual inductance.

294. When an e.m.f. is induced in a coil by a changing current in an adjacent coil in an independent electric circuit, what is the effect termed?

295. When the current in the field producing coil is made to change uniformly at the rate of 1 ampere per second and the induced e.m.f. in the adjacent coil is 1 volt what is the coefficient of the mutual inductance of the adjacent coil said to be?

296. What is the practical unit of mutual inductance called and how is it designated?

297. When do the phenomena of self-induction and mutual induction occur?

298. How do these occur in direct current circuits?

Units of Measurement for Current, Voltage and Resistance

Unit of current.

299. What is current?

300. What is the practical unit of current, how is it designated and described?

301. What is a milliampere?

302. What is the designation for current?

Unit of electromotive force or voltage.

303. What is electromotive force and how is it expressed?

304. Define the volt.

305. What is a millivolt?

306. What is a kilovolt?

307. What is the designation of electromotive force or voltage?

Unit of resistance.

308. What is resistance?

309. What is the practical unit of resistance, how is it designated and described?

310. What is a microhm?

311. What is a megohm?

312. What is the designation for resistance?

International units.

313. Define an ampere.

314. Define an ohm.

315. Why were the international units developed and when?

316. On what system do the great standardizing laboratories of the world base their measurements and why?

Wires and Cables

Unit of wire measurement.

317. What is the standard of wire measurement and how described?

318. How many of these wires, laid side by side, would form a layer one inch wide and one one-thousandth of an inch thick?

319. What would be the size of a pile, the number of wires and the cross-sectional area in circular mils with one thousand such layers piled on each other?

320. To what size solid cylindrical wire are one million c.m. equal?

321. If the diameter of a wire in mils is squared, what is the result?

322. What does Fig. 15 show?

Resistance, and specific resistance or resistivity.

323. How is resistance defined?

324. If a cable one mile long has a known value of resistance, what resistance will one-half of the cable have and what will be the resistance of one two miles long, assuming the cross-sectional area and the material remain constant throughout its length?

325. If a cable one mile long of known resistance has a cross-sectional area of one-half square inch, how will a similar cable one mile long but having twice the cross-sectional area compare?

326. How does hard drawing and annealing of wire affect its resistance?

327. How do impurities in the conductor material affect the resistance?

328. How is the resistance of metallic conductors affected by increase in temperature?

329. When stating a resistance value what is it essential to consider?

330. In practice how is the temperature value considered?

331. What is the general expression of the formula for resistance?

332. What is the constant known as, and upon what does it depend?

333. If centimeter units are used, what is the specific resistance?

334. In practice, what unit of cross-sectional area is most generally used?

335. When the circular mil is used as the unit of cross-sectional area, what is generally used as the unit of length?

336. What is the specific resistance of pure annealed copper at 25 degrees Centigrade (77 degrees Fahrenheit)?

337. What is the dimension of a circular mil-foot?

338. What is the formula for resistance based on the circular mil-foot at 25 degrees Centigrade (77 degrees Fahrenheit)?

Conductance, and specific conductance or conductivity.

339. How is the conductance of a wire defined?

340. What is the unit of conductance?

341. What is the conductance of a wire having 1 ohm resistance? Two ohms resistance?

342. What is the formula for conductance?

343. What is the constant in this formula, what is it known as, and upon what does it depend?

Volume-conductivity and mass-conductivity.

344. In practice, for what are conductivities used?

345. What material has been chosen as a standard to compare others with, and how is its conductivity considered?

346. Upon what basis may conductor materials be compared?

347. If the resistance per circular mil-foot of a given material is four times that of copper at the same temperature, what per cent is its volume-conductivity said to be, and how great would the cross-sectional area of a conductor made of this material have to be in order to have as low a resistance as copper?

348. Where are volume-conductivities useful, and where may they be compared on an equal-mass basis?

349. If the resistance of a uniform wire, of a given material one metre long and weighing one gram is twice the resistance of a uniform wire of pure annealed copper, one metre long and weighing one gram, at the same temperature, how does the mass-conductivity compare?

350. To what does the term "conductivity," as commonly used, in reference to conductors, refer?

Working Table

351. In the working wire table, how does a wire, three gage numbers removed from a given wire, compare with the given wire as to resistance, mass per unit length, and cross-section (a) if the wire is larger than the given wire; (b) if smaller?

The effect of change in temperature on the value of resistance.

352. For what temperature are wire tables compiled, and what temperature is used in the working wire table shown?

353. What formula is used for converting the resistance values shown in the working wire table for temperatures other than 25 degrees Centigrade (77 degrees Fahrenheit)?

Calculation of Circuits—Ohm's Law

Relation of current, voltage and resistance in a circuit.

354. Name and give the law governing the flow of current in a circuit. How is it expressed?

Resistances in series.

355. How is the resistance of a circuit calculated that has several resistances in series? How is it expressed?

Resistances in multiple.

356. How is the resistance of a circuit calculated that has several resistances in multiple? How is it expressed?

Resistances in multiple-series.

357. How is the resistance of a circuit calculated that has several resistances in multiple-series? How is it expressed?

Use of voltmeter.

358. How is the electromotive force between any two points of a circuit measured?

359. How are the connections for the voltmeter made?

360. Where do the voltmeters V_1 and V_2 measure the electromotive force as shown in Fig. 19 and what is indicated by voltmeter V_2?

Use of ammeter.

361. When the current in a circuit is to be measured, how is the ammeter connected?

362. When the amount of current in a circuit is very large, what provision is made to overcome the necessity for a cumbersome and expensive ammeter?

363. Describe the connections for the ammeter and its shunt, as shown in Fig. 21.

Voltage drop in a circuit with several resistances in series.

364. Calculate the electromotive force required to cause two amperes to flow through the circuit shown in Fig. 16, assuming the values of the resistances R_1, R_2, and R_3 to be 50 ohms, 100 ohms, and 80 ohms, respectively.

Voltage drop in a circuit with resistances in multiple.

365. Calculate the voltage impressed on the loads R_1 and R_2 in the circuit shown in Fig. 22.

Current in a circuit of known resistance.

366. Calculate the current flowing in the circuit of known resistance shown in Fig. 23.

367. Calculate the useful voltage of the cell shown in Fig. 23.

Current flowing in a circuit of known resistance with cells in series.

368. If a voltage higher than that of one cell is required, how can it be obtained?

369. How will the current output of the series battery thus formed compare with the current output of one cell?

370. Calculate the current flowing in the circuit of known resistance and cells in series shown in Fig. 24.

Current flowing in a circuit of known resistance with cells in multiple.

371. If two similar cells are connected in multiple, how will the current compare with that of an individual cell, and how will the voltage compare?

372. Calculate the current flowing in the circuit of known resistance with cells in multiple, shown in Fig. 25.

Current flowing in a circuit of known resistance with cells in multiple-series.

373. Calculate the current flowing in the circuit of known resistance with cells in multiple-series, shown in Fig. 26.

Quantity of Electricity

Coulomb.

374. What is the practical unit of quantity of electricity and how is it defined? How is it designated?

Ampere-hour.

375. How is the ampere-hour used and how does it compare with the coulomb?

376. How is the ampere-hour used to express the capacity of storage cells? Give an example.

Capacity—Condensers

Electrical capacity.

377. What are condensers used for?

378. What was the original condenser?

379. Describe the present-day condenser.

380. Describe some simple condensers.

381. How does B receive a positive and C a negative charge as shown in Fig. 27?

382. What determines the capacity of a condenser?

383. Will the plates retain their charge if disconnected from the battery?

384. How is the condenser discharged?

Dielectric strength.

385. How may the dielectric strength of any insulating substance be tested?

386. How is the dielectric strength of insulating material determined?

387. How is the value of the dielectric strength found?

Unit of capacity.

388. How is the capacity of a condenser measured?

389. What is the practical unit of capacity?

390. When has a condenser a capacity of 1 farad?

391. Why is the microfarad generally used in practical work instead of the farad?

392. What is the designation of capacity?

Electro-Dynamics

Electricity and mechanical motion; dynamos and motors.

393. What was the result of the discovery that cutting magnetic lines of force with a conductor would produce an electromotive force in the conductor?

394. How do the voltage and current flow in direct and alternating current compare?

395. State the difference between alternating current and direct current.

396. What is an alternation? A cycle?

397. What is the name of the machine which transforms mechanical energy into electrical energy?

398. What is the machine called which transforms electrical energy into mechanical energy?

399. For what purposes have solenoids been used in signaling?

Energy and power.

400. What is the definition of power?

Unit of power.

401. To what is the power in any part of an electrical circuit proportional?

402. Define the watt.

403. How is the kilowatt designated and to what is it equal?

404. How many watts correspond to 1 horsepower?

405. What is the designation for power?

Unit of energy.

406. How is the amount of electrical energy transformed to another form of energy determined?

407. When the power, or rate at which work is being done, is 1 watt, what is the work done in 1 second called and what is it known as?

408. What is often used to designate time and power, and how does it compare with joules?

409. What is a still larger unit used to designate electrical energy?

410. How is the joule represented?

Unit of heat.

411. Define the unit of heat as used in the metric system.

412. Define the unit of heat as used in the British system.

Energy distribution.

413. What two methods may be used in finding watts?

414. How is the formula $P = I^2R$ derived and what does it represent?

Power loss from resistance.

415. What is the effect when an electric current flows through a conductor, with what does the effect compare and what is the result?

416. With what does the voltage necessary to cause the current to flow compare, and what is it called?

417. Upon what has it been proven that the resistance voltage of a solid or liquid conductor depends?

418. Does the resistance voltage have any relation to the properties of external conductors, surrounding insulators or other external circumstances?

419. To what is the power lost in a wire as heat proportional, and what is it known as?

Electrical distributing systems.

420. What does Fig. 28 represent?

(*a*) *Power generated.*

421. Calculate the power generated by the system shown in Fig. 28 where the voltmeter (V) indicates 100 volts between the positive and negative conductors and the ammeter (A) indicates an output of 10 amperes through the conductors.

(*b*) *Drop of voltage in line.*

422. By what formula is the drop in voltage found?

423. Calculate the drop in voltage between the power house and the factory assuming that the resistance of the conductors is 2 ohms. What is the voltage at the factory?

(*c*) *Loss of power as heat in transmission line.*

424. Calculate the loss of power as heat in the transmission line.

425. If the conductor is not large enough to carry the current, that is, if its resistance is high and it has consequently a high I^2R loss, what may be the effect upon the conductor?

426. Why is the amount of current limited for certain sizes of conductors with certain insulations?

Power consumed by lamps.

427. When a lamp is rated at 50 watts for 110 volts what does it mean?

428. Calculate the current used in this lamp and its resistance.

429. Calculate the watts consumed by the same lamp when the voltage is reduced to 100 volts.