CHAPTER NINE
Capacitance

In Chapter Eight, you learned that inductance opposes any change in current. Capacitance is the property of an electric circuit that resists, or opposes, any change of voltage in a circuit. That is, if applied voltage is increased, capacitance opposes the change and delays the voltage increase across the circuit. If applied voltage is decreased, capacitance tends to maintain the higher original voltage across the circuit, thus delaying the decrease. Consequently, the most noticeable effect of capacitance in a circuit is that voltage can neither increase nor decrease as rapidly in a capacitive circuit as it can in a circuit that does not include capacitance.

Capacitance is also defined as that property of a circuit that enables energy to be stored in an electric field. Unplanned, or "natural," capacitance exists in many electric circuits. In this book, however, we are concerned only with capacitance that is designed into the circuit by means of devices called capacitors.

When you have finished this chapter you will be able to:

- describe the construction of a capacitor;
- explain the factors affecting the value of capacitance;
- describe the charge and discharge of circuits that include capacitance and resistance;
- calculate RC time constants;
- calculate total, or equivalent, values of capacitance in series or in parallel;
- calculate the working voltage of a capacitor; and,
- describe some common types of capacitors.

The Capacitor

1. The capacitor is essentially a device that stores electrical energy. It can be charged and discharged, as we shall see later. The capacitor is a manufactured device that introduces capacitance to a circuit, just as the resistor presents resistance to current flow and the inductor greatly increases the inductance of a conductor. The capacitor is used in a number of ways in electrical circuits. It may block d-c in a-c portions of a circuit, since it is effectively a barrier to direct current (but not to alternating current). It may be part of a tuned circuit—one such application is in

the tuning of a radio to a particular station. It may be used to filter a-c out of a d-c circuit. Most of these are advanced applications that are beyond the scope of this book; however, a basic understanding of capacitance is necessary to the fundamentals of alternating current theory. Let's start with the construction of the capacitor.

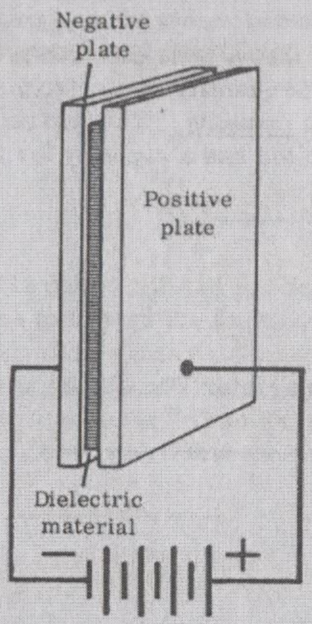

Figure 9-1. A simple capacitor.

Refer to Figure 9-1 for Frames 1 through 6.

A capacitor in its simplest form is shown connected to a battery in Figure 9-1. It consists of two metal plates, a ________________ plate and a ________________ plate, separated by a thin layer of insulation called the ________________________.

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2. You learned early in this book that a body with an excess of electrons is negatively charged, while a body with a deficiency of electrons is positively charged. When a capacitor is connected across a voltage source, such as a battery, the voltage forces electrons onto one plate, making it (negative/positive) ________________.

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3. The other terminal of the battery pulls electrons off the other plate, making it ____________.

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4. Electrons cannot flow through the dielectric, because it is an insulator. Since it takes a definite quantity of electrons to "fill up" (charge) a capacitor, it is said to have capacity. This characteristic is referred to as capacitance. A capacitor has a capacity for a certain quantity of what?

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5. What do we call the characteristic of a capacitor that enables it to take a charge? ____________

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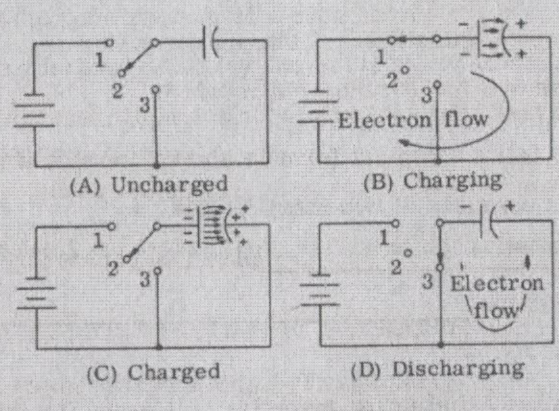

Figure 9-2. Capacitor action.

Refer to Figure 9-2 for Frames 6 through 13.

6. The basic action of a capacitor is illustrated in four different states in Figure 9-2. Note that this figure introduces the symbol for a capacitor. The symbol is most clearly seen in View A. Draw the symbol for a capacitor.

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(Note:

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7. The three-position switch has one open and two closed positions. As shown in View A, the capacitor is in a balanced, or uncharged, condition. There is no way to place a charge on its plates because the battery is not in the circuit. The battery is connected into the circuit when the switch is placed in what position? ______

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8. When the switch is set to position 1, as in View B, a surge of battery current immediately begins to charge the capacitor. There is only a <u>momentary</u> surge of electrons, after which direct current is completely stopped by the dielectric of the capacitor. Free electrons do not pass from one plate of the capacitor to the other. When we say that a capacitor has a charge (is unbalanced), do we mean that the charges on the two plates are equal or unequal? ______________

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9. The natural tendency of the capacitor is to restore its own balance by discharging through the battery in a clockwise direction (View B). This tendency is small at first because the imbalance between the two plates is small, but the tendency to discharge becomes stronger as the capacitor is charging (that is, as the imbalance becomes greater).

In your study of inductance, you learned that the action of a magnetic field induces a counter emf in a conductor. The tendency of a capacitor to discharge is also a counter emf. This tendency results from the difference in potential between the two plates, which have different charges. Some current actually flows in the circuit as shown in View B, because the battery is moving electrons onto one plate and pulling them away from the other. When the counter emf of the capacitor has risen to equal the battery voltage, we say that the capacitor is charged. At this point, there is no more room for electrons on its negative plate, and the battery cannot pull any more electrons away from its positive plate. This condition is shown in View C. When the capacitor is fully charged, what happens to the movement of electrons in the circuit? ____________________

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10. When the capacitor is fully charged (View C), the switch is returned to position 2. The capacitor is now a source of potential energy, somewhat as if it were a charged battery. Because of the unequal charges on its plates, there is a difference in potential between the negatively charged plate of the capacitor and terminal 3 of the switch. When the switch is set to position 3 (View D), a circuit is completed, and the charged capacitor is the source voltage. When the switch is set to position 3, what happens in the circuit? ______________________________

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11. Current flows during the time the capacitor is discharging. The capacitor is completely discharged when the charges on its plates are again equal. What happens to the current in the circuit when the discharge is complete?

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12. In your study of inductance, you learned that magnetic lines of force are associated with an inductor. Lines of force are also associated with a capacitor, and they are shown between the plates of the capacitor in Views B and C of Figure 9-2. These lines of force are not magnetic; they are <u>electrostatic</u>, or simply electric. They originate on the ____________ plate and terminate on the ________________ plate.

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13. The lines of force are assumed to follow the same paths that negatively charged bodies (or electrons) would take if they were free to move. The lines of force would be present even if the plates of a capacitor were enclosed in a perfect vacuum. Electric lines of force cannot exist in a metallic conductor to any great extent, because equalizing currents are free to flow within the metal. What part of the capacitor prevents the flow of equalizing currents? ______________________________

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Dielectric Materials

14. Various materials differ in their ability to support electric lines of force (flux); that is, to serve as dielectric materials for a capacitor. Materials are rated in their ability to support electric flux in terms of a number called a dielectric constant. The higher the value of the dielectric constant (other factors being equal), the better the material serves as a dielectric. Dry air is the standard by which other materials are rated. In inductors, the permeability of the core material was also related to that of dry air, which has a permeability (μ) of 1. Similarly, you should expect the dielectric constant of dry air to be ______.

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15. Some of the dielectric materials used in capacitors may surprise you. You have probably thought of air as a good insulator, and normally it is. But the plates of most capacitors are very closely spaced. If air were used in such capacitors, the current would arc (jump) across the plates. All of the materials in the list below are used as dielectrics in capacitors.

Which is the best dielectric? ______________________

Material	Dielectric-constant (Average values)
Air	1
Polystyrene........	2.5
Paraffin paper......	3.5
Mica	6
Flint glass.........	9.9
Methyl alcohol	35
Glycerin...........	56.2
Pure water	81

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Unit of Capacitance

16. The unit for capacitance, C, is the farad (named for Michael Faraday), abbreviated f. The capacitance of a capacitor is proportional to the quantity of charge that can be stored in it for each volt difference in potential between its plates. A capacitor has a capacitance of 1 farad when a quantity of charge of 1 coulomb imparted to it raises its potential 1 volt. (One

coulomb is equal to 6.28×10^{18} electrons.) This relationship may be stated mathematically as

$$C = \frac{Q}{E}$$

where C is the capacitance in farads, Q is the quantity of charge in coulombs, and E is the difference in potential in volts. A capacitor of one farad would be of enormous dimensions, so two practical units are used instead: the microfarad (μf) and the picofarad (pf). The picofarad is one millionth of a microfarad, or 1×10^{-12} farads. (If you are a bit weak on negative powers of 10, 1×10^{-12} is the same as 0.000000000001, or a decimal point followed by 11 zeroes and a 1.) A microfarad (1×10^{-6} farads) corresponds to a microhenry in inductance (Chapter Eight). A capacitor of 1 μf has a capacitance of one- (thousandth/millionth)

__________________ of a farad.

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Factors Affecting the Value of Capacitance

17. The capacitance of a capacitor depends on three factors:
    1. The area of the plates
    2. The distance between the plates
    3. The dielectric constant of the material between the plates

    A greater plate area provides a greater capacity to store free electrons. When the area of the plates is increased, what happens to capacitance? __________________

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18. Capacitance is directly proportional to the flux field between the plates. This field is stronger when the plates are more closely spaced. As the distance between the plates is increased, what happens to capacitance?

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19. Capacitance is directly related to the ability of the dielectric to prevent the movement of free electrons between the places. If the dielectric constant is increased, what happens to capacitance? __________________

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20. Name the three factors affecting the value of capacitance, and state whether capacitance will be increased or decreased with an increase of each factor.

1. ________________________________

2. ________________________________

3. ________________________________

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<u>Charge and Discharge of a Resistive-Capacitive (R-C) Series Circuit</u>

21. According to Ohm's Law, the voltage across a resistance is equal to the current through it multiplied by the value of the resistance (E = IR). This means that a voltage will be developed across a resistance only when

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22. If no current flows through a resistor, what is the voltage drop across the resistor? __________

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23. View A of Figure 9-3 on the next page shows a voltage divider circuit consisting of a resistor (R) and a capacitor (C). The source voltage (E_S) is supplied by a battery. Switches S_1 and S_2 are "ganged" (indicated by a dashed line) so that one switch is opened when the other is closed.

View B shows the graphs for the source voltage (E_S), the charge current (i_c), the difference in potential across the resistor (e_R) during charge, and the difference in potential between the plates of the capacitor (e_C) during charge. View C shows the graphs for the source voltage (E_S), the discharge current (i_d), the difference in potential across the resistor (e_R) during discharge, and the difference in potential between the plates of the capacitor (e_C) during discharge. The time lines also serve as the zero lines for the charge and discharge curves.

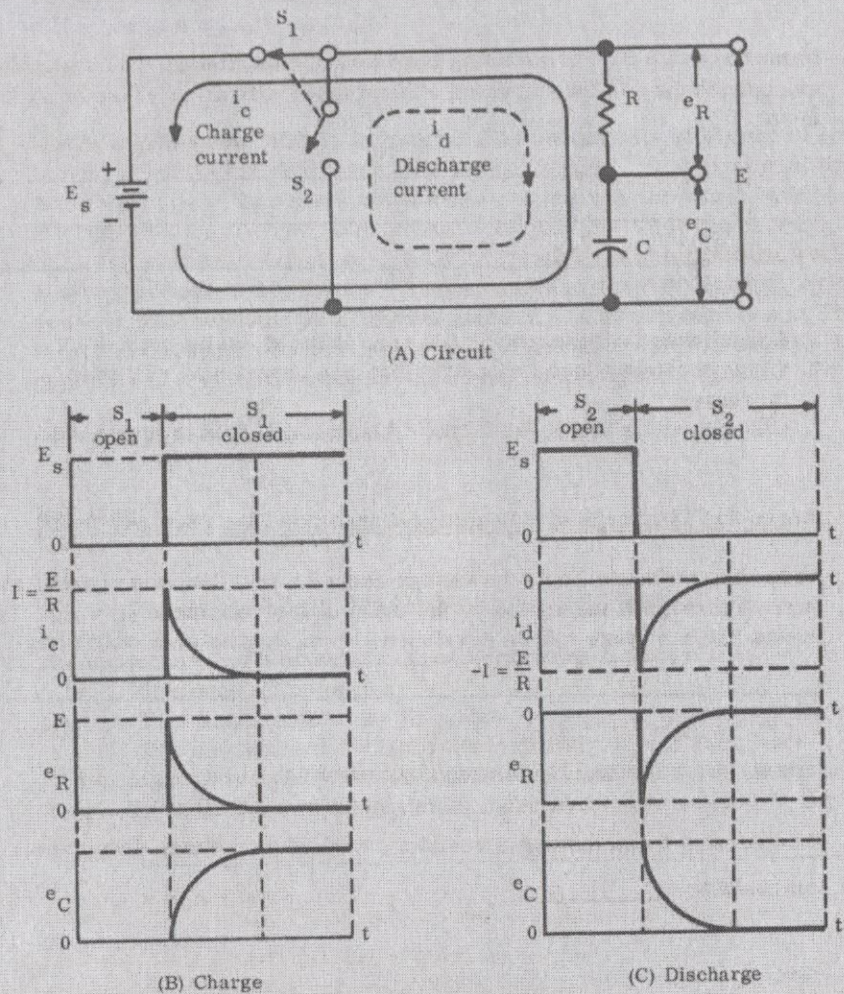

Figure 9-3. Charge and discharge of an R-C series circuit.

Refer to Figure 9-3 for Frames 23 through 39.

is because the time lines also serve as the zero lines for the charge and discharge curves. By displacing the zero lines, we can compare the total increase or decrease for each value.

For the moment, look at View A only. When is the battery connected into the circuit? ______________________________

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24. When S_1 is closed, electrons flow counterclockwise around the circuit containing the battery, the resistor, and the capacitor (View A). Remember that current does not flow through the capacitor, because its dielectric is an insulator. The current flow results from the fact that electrons accumulate on the negative plate of the capacitor and are pulled away from the positive plate as they are attracted by the positive terminal of the battery. Current flows momentarily through the resistor, but at first no difference in potential exists between the plates of the capacitor. At the instant current begins to flow, what is the relationship between the voltage drop across the resistor and the battery (source) voltage? __________

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25. The electron flow stops when the capacitor is fully charged; that is, when the voltage across the capacitor (difference in potential between its plates) is equal to the battery voltage. Why is there now no current flow through the resistor? ______________________________

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26. There is a voltage drop across the resistor only as long as the capacitor is (charging/discharging) ____________________.

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27. View B shows the division of the battery voltage E_s between the resistance and capacitance at all times during the charge process. Since the circuit is a voltage divider whose only components outside the battery are R and C, the sum of e_R and e_C will at every instant be equal to __________.

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28. View B shows graphs of the battery voltage E_s, the charge current i_c, and the voltage drops (differences in potential) across the resistor (e_R) and the capacitor (e_C). Remember that i_c is <u>not</u> the current through the capacitor; a capacitor is in effect an "open circuit" to direct current. (If this is confusing, review the explanation in Frame 24.) All three values are plotted against the same time. At the instant current begins to flow (S_1 closed), the entire source voltage E_s appears across (R/C) ________ and the voltage across C is ________.

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29. The current flowing in the circuit soon charges the capacitor. Because the voltage on the capacitor is proportional to its charge, a voltage e_C will appear across the capacitor. This voltage opposes the battery voltage; that is, these two voltages "buck" each other. As a result, the voltage e_R across the resistor is $E_s - e_C$ (Kirchhoff's Law of Voltages). According to Ohm's Law, $e_R = i_c R$. Because E_s is fixed, as i_c decreases, what happens to e_C? ____________________

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30. The charging process continues until the capacitor is fully charged. At that point, e_C = (E_s/e_R) ________.

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31. When the capacitor is fully charged, e_R = ________.

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32. View C shows the graphs of E_s, e_R, e_C, and i_d (discharge current). When the capacitor is fully charged and S_2 is open, all circuit values are as shown at the end of the charge cycle in View B. When S_2 is closed, the discharge cycle begins. At this point, what is the value of E_s in the circuit? ________

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33. Since the discharge current i_d flows in a direction opposite to that of the charge current, its equation is shown as $-I = \frac{E}{R}$. At the instant S_2 is closed, what happens to the capacitor? ____________________

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34. The graphs in Figure 9-3 show values between zero and maximum, with no specific magnitudes indicated. What is the value of e_C at the instant S_2 is closed? ____________________

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35. When S_2 is closed, the discharge current i_d is maximum and decreases to zero as the capacitor loses its charge. What happens to e_R during the discharge cycle? ____________________

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36. When C begins to discharge, what happens to the charge current? ____________________

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37. When S_2 is closed, S_1 is opened and the battery is removed from the circuit. What provides the source voltage for current flow during the discharge cycle? ____________________

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38. During the discharge cycle, e_R is equal and opposite to ________.

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39. As the capacitor discharges, e_C decreases. Since e_C is the source voltage during discharge, i_d also decreases. In accordance with Ohm's Law, e_R also decreases. At the end of the discharge cycle, all values are

zero. The buildup of voltage (charge) on a capacitor and its decay (discharge) do not occur instantly, because the counter emf of a capacitor opposes any change of voltage in the circuit. The graphs in View C show that the voltages drop rapidly from their initial values when C begins to discharge and then approach zero more slowly. When i_d, e_R, and e_C all reach zero, what is the state of the capacitor? ________________

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The actual time it takes a capacitor to charge or discharge is important in advanced electricity and electronics. Since the charge or discharge time depends on the values of capacitance and resistance, a circuit can be designed for the proper timing of certain electrical events. We will study the RC time constant in the next section.

This is a convenient place to take a break.

RC Time Constant

40. Just as an L/R time constant was associated with inductance, an RC time constant expresses the charge and discharge times for a capacitor. You should recognize the values, since they correspond to the values for an R-L series circuit. The RC time constant is the time required to charge a capacitor to 63.2 percent of its maximum voltage or to discharge it to ________ percent of its maximum voltage.

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41. The value of the time constant in seconds is equal to the product of the circuit resistance in ohms and its capacitance in farads.

R (ohms) x C (farads) = t (seconds)

This basic equation is not very useful, because capacitance is never given in farads. However, resistance is often in megohms (the prefix "meg-" means million), and capacitance is usually in microfarads or picofarads. Therefore, the following relations are useful in calculating the RC time constant.

R (megohms) x C (microfarads) = t (seconds)

R (ohms) x C (microfarads) = t (microseconds)

R (megohms) x C (picofarads) = t (microseconds)

One set of values illustrates this in Figure 9-4, on the following page. A circuit is shown with the values of R and C assigned. Look at the illustration, then answer the question that follows it.

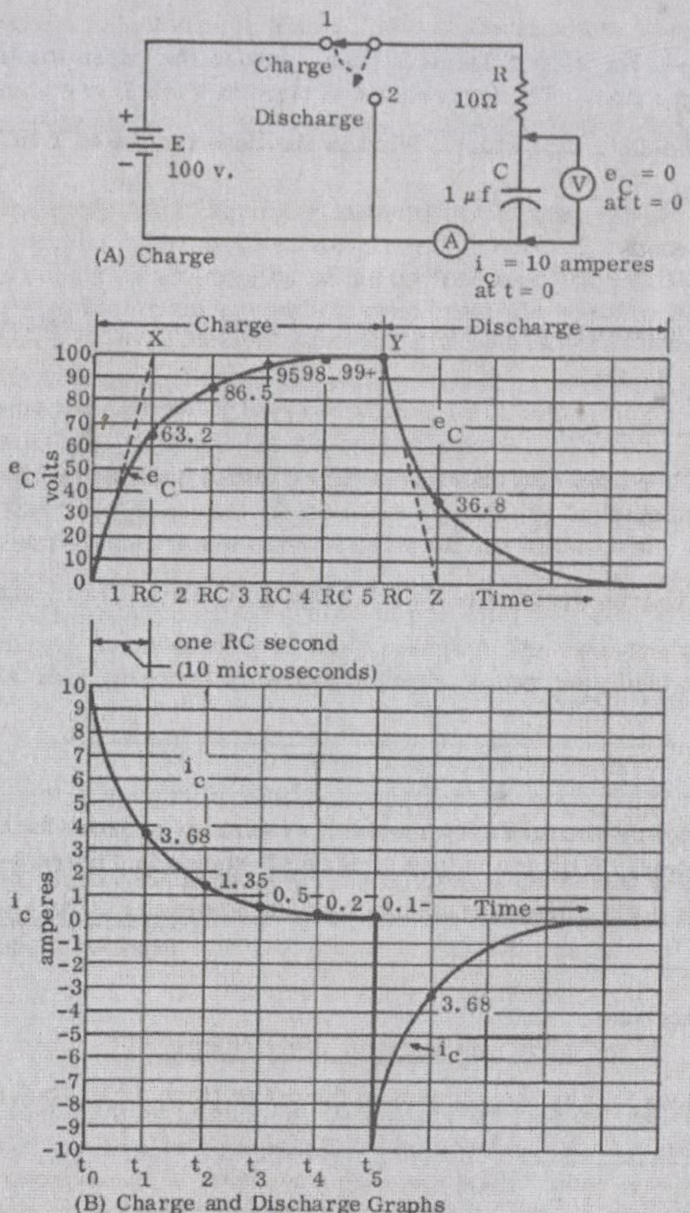

Figure 9-4. RC time constant.

Refer to Figure 9-4 for Frames 41 through 49.

What units are shown for the following values?

resistance ____________________

capacitance ____________________

time ____________________

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42. In Figure 9-4, the rise in the voltage e_C across the capacitor is plotted against a time line. The increments of time in View B are shown in time constants (1 RC, 2 RC, etc.). What is the time from 0 to 1 RC? ______

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43. When e_C reaches 63.2 v., what is the voltage across the resistor?

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(Remember: The two voltages added must equal the source voltage, 100 v.)

44. During the charge cycle, the switch in the R-C circuit is in what position?

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45. As the capacitor charges, the momentary current i_c from the battery rapidly decreases. With the values of R and C shown in Figure 9-4, how long does it take the current to decrease to 3.68 a.? ______

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46. How long does it take the current to decrease from 10 a. to 0.5 a.?

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47. If R in the circuit is 8Ω and C is 1.5 μf, how long will it take the voltage across the capacitor (e_C) to reach 63.2 v.? ______

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48. R = 10Ω and C = 2 μf. How long will it take the capacitor to charge to 98 percent of full charge? (Hint: Look at the graph in View A.) __________

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49. The mathematics of the RC time constant is very simple. To visualize what actually happens in an RC circuit, however, you must remember that a capacitor charges by piling up free electrons on the negative plate, while free electrons are pulled away from the positive plate. If the capacitance is large, more electrons are accumulated before the capacitor is fully charged. During discharge, a large resistance presents a greater obstacle to the flow of free electrons, so it takes longer for the capacitor to discharge, or drain off the free electrons. Therefore, the RC time constant is greater if the capacitance is large (because there are more free electrons to drain off) or if the resistance is large (because a small current requires more time to drain off the electrons). Remember that a capacitor charges quickly at first and then more slowly reaches its maximum voltage, or difference in potential between its plates; it also discharges more quickly at first, and then the rate slows down. Define the RC time constant in terms of these charge and discharge characteristics. ____

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Capacitors in Parallel and in Series

50. Like resistors or inductors, capacitors may be connected in series, in parallel, or in a series-parallel combination. As we shall see, however, total capacitance is found in a different way. View A of Figure 9-5, which appears on the following page, shows three capacitors connected in parallel across a battery. If the voltage across C_1 is 100 v., what is the voltage across C_2? __________

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51. We have seen that one factor affecting capacitance is the area of the plates. All the positive plates in Figure 9-5 are connected together and are electrically at the same point, and all the negative plates are also

electrically "tied" together. If all three capacitors are identical, the total plate area of the three capacitors is how many times larger than the plate area of a single capacitor? ____________

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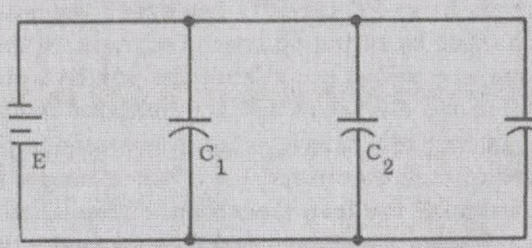
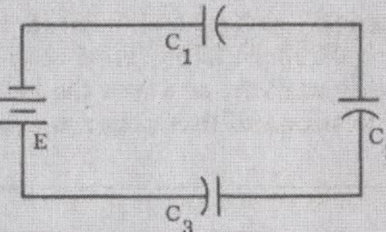


$$C_t = C_1 + C_2 + C_3$$

(A) Parallel



$$\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

(B) Series

Figure 9-5. Capacitors in parallel and in series.

Refer to Figure 9-5 for Frames 50 through 60

52. Since the three capacitors are identical, both plate spacing and dielectric are also identical. All three positive plates are connected, and all three negative plates are also connected. The three capacitors could be thought of as a single ____________________.

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53. Since the three capacitors are identical, and their like plates are connected, they could be thought of as a single capacitor. If the capacitance of any one of the three capacitors is C, how might you express the capacitance of the combined capacitors? ____________________

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54. If the three capacitors are of different values, they could still be thought of as different parts of a single capacitor. In this case, total capacitance is the sum of the individual capacitances. Suppose the capacitors in Figure 9-5, View A, have the following values: 5 μf, 10 μf, and 15 μf. What is the total capacitance? __________

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55. Look at the circuit in View B of Figure 9-5. The equation for total capacitance of capacitors in series (shown below the circuit) resembles the equation for total resistance of resistors in ____________________.

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56. In View B, $C_1 = 5$ μf, $C_2 = 10$ μf, and $C_3 = 20$ μf.

$C_t =$ __________

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57. Two capacitors in series have values of 2 μf and 4 μf. What is the total capacitance? (Hint: You can use the product-over-sum method with capacitance, too.) __________

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58. Write the formula for total, or equivalent, series capacitance.

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59. Write the formula for total, or equivalent, parallel capacitance.

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60. You have been conditioned to calculate resistances in series by simple addition and to use the more complicated formula for calculating parallel resistance. This conditioning was reinforced by the fact that series and parallel inductances are calculated in the same way. Therefore, it is easy to forget that the rules are not the same for the calculation of total capacitance. Make a general statement about the calculation of capacitance, both series and parallel, in comparison with the calculation of resistance. ________________________________

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Voltage Rating of Capacitors

61. In selecting capacitors for an electrical circuit, you must decide not only the values of capacitance but the amount of voltage to which the capacitors will be subjected. As with any other electrical component, a capacitor is designed to withstand a certain maximum voltage. If this voltage is exceeded, current will arc (jump) between the plates, despite the insulation of the dielectric. This current will be great enough to damage the capacitor. The maximum voltage that can be steadily applied to a capacitor without danger of arc-over is its working voltage. The working voltage depends on the physical construction of the capacitor and is indicated by the manufacturer. When a capacitor is selected, its working voltage should be at least 50 percent greater than the maximum voltage it will encounter in the circuit. (This additional 50 percent is a standard margin of safety.) If a capacitor is expected to have a maximum of 100 v. applied to it, its working voltage should be at least __________.

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62. What may happen if the working voltage of a capacitor is too low?

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The capacitor may be damaged.

63. A capacitor is to be used in a circuit in which it will be subjected to 500 v. Its minimum working voltage should be __________.

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Types of Capacitors

64. There are two major groups of capacitors: fixed and variable. The names describe the difference between them. The fixed capacitor has a set value of capacitance that is determined by its construction. The construction of the variable capacitor allows a range of capacitances. Within this range, the desired value of capacitance is obtained by some mechanical means, such as by adjusting a screw or turning a shaft, as you do with the tuning knob on a radio. If you are designing a circuit in which some electrical effect is achieved by manually changing the capacitance, you need to use at least one of which type of capacitor? ________________

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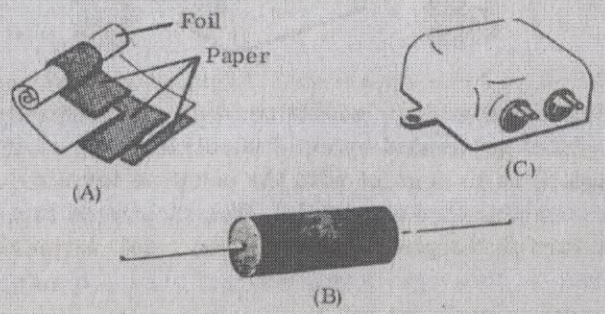
65. Capacitors come in a wide variety of sizes and constructions. Some capacitors used in extremely high-voltage applications may be 2 or 3 feet high, although most are so small that several may be comfortably held in one hand. Capacitors may be classified according to the type of material used as the dielectric, such as paper, oil, mica, and electrolyte. A common capacitor type is the paper capacitor, whose plates are strips of metal foil separated by waxed paper. The strips of foil and paper are rolled together to form a cylindrical cartridge, which is then sealed in wax to keep out moisture and to prevent corrosion and leakage. A metal lead is soldered to each plate and extends from the cylinder at either end. The illustration below shows the construction of a paper capacitor (A), the capacitor encased in cardboard (B), and a more rugged type of paper capacitor (C) that is hermetically sealed in a metal container.



In a paper capacitor, what part of the capacitor is made of paper?

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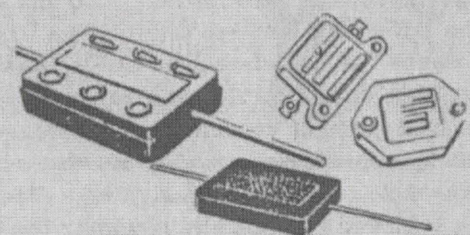
66. Oil capacitors are used at higher voltages, because a paper dielectric might not provide sufficient insulation to prevent arcing across the plates. These capacitors, whose dielectric is paper impregnated with oil, are used mostly in radio and radar transmitters. Mica is a widely used dielectric material. Some typical mica capacitors are shown here.



Name two types of capacitors that have better dielectrics than plain paper capacitors. ______________________________

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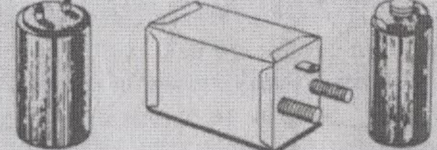
67. For capacitances greater than a few microfarads, the physical size of a paper or mica capacitor becomes excessive. However, capacitors that use an electrolyte as a dielectric may obtain large capacitances with small physical dimensions. Unlike most other capacitors, electrolytic capacitors are marked with polarity (+ and −) and must be connected as indicated. Shown here are some typical electrolytic capacitors.



The electrolytic capacitor, widely used in electronic circuits, consists of two metal plates separated by an electrolyte. The electrolyte, either paste or liquid, is in contact with the negative terminal, and this combination forms the negative electrode. The dielectric is a very thin film of oxide deposited on the positive electrode, which is an aluminum sheet.

In which of the following capacitors is polarity of connection important?

_______ electrolytic

_______ oil

_______ mica

_______ paper

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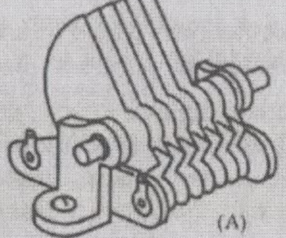
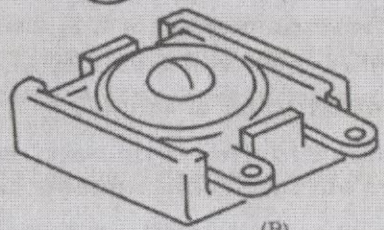
68. So far we have discussed only fixed capacitors. Variable capacitors, as the name implies, may be adjusted to change the capacitance. A common application is the variable capacitor (A) in the drawing below. This type of capacitor is commonly seen in ordinary radios and is varied as stations are selected with the tuning knob. A screw-adjust may also be used to vary the capacitance, as shown in (B).



(A)



(B)

Since the plates of a variable capacitor must be free to move, a dielectric such as paper or mica cannot be used. Can you guess what is used as the dielectric of a variable capacitor? ____________________

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n ically.)

Only the most common types of capacitors have been described. Others, such as the ceramic, are coming into use as the technology advances.

In this chapter you have learned how a capacitor is constructed as well as some of the factors that affect capacitance. You have seen how capacitors are charged and discharged and how the charge and discharge times are related to the RC time constant.

You have learned to calculate RC time constants, total capacitance in series and in parallel, and the working voltage of a capacitor.

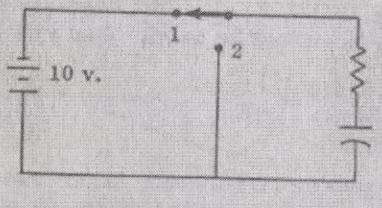
Finally, you have been introduced to some of the more common types of capacitors.

When you feel that you understand the material in this chapter, go on to the Self-Test.

Self-Test

The following questions will test your understanding of Chapter Nine. Write your answers on a separate piece of paper and compare them with the answers provided following the test.

1. Describe the basic components of any capacitor.
2. Draw the schematic symbol for a capacitor.
3. Electrons do not pass between the plates of a capacitor, yet current flows in the circuit as the capacitor is charged. How is this possible?
4. When the battery is removed from a circuit that includes a charged capacitor, the capacitor will discharge if a complete circuit is provided for current flow. Since there is no battery, what causes current to flow during discharge, and when will the current cease to flow?
5. Polystyrene has a dielectric constant of 2.5, while that of paraffin paper is 3.5. Which material is the better dielectric?
6. One microfarad is what fraction of a farad?
7. Name the three factors that affect capacitance and state whether an <u>increase</u> in that factor will increase or decrease capacitance.
8. The capacitor in the circuit below will either charge or discharge, depending on the position of the switch.



(a) Is position 1 of the switch the charge or discharge position?
(b) At the instant charging begins, what is the difference in potential across the resistor?
(c) At the instant charging begins, what is the difference in potential across the capacitor?

(d) At the instant the switch is moved to position 2 (assuming the capacitor is fully charged), what is the difference in potential across the capacitor?

(e) When the switch is in position 2, when will current stop flowing?

9. Define the RC time constant.

10. An RC circuit includes a 25-ohm resistor, a 5-microfarad capacitor, and a 100-volt battery. How long will it take the voltage across the capacitor to reach 63.2 v. ?

11. A 50-microfarad capacitor in series with a 3-kilohm resistor is connected to a 200-volt d-c source. What is the RC time constant of the circuit?

12. What is the total capacitance of two 50-microfarad capacitors connected in series?

13. What is the total capacitance of a series combination of two 100-microfarad capacitors connected in parallel with a 75-microfarad capacitor?

14. The highest voltage to be applied to a capacitor in a certain circuit is 300 v. What should be the minimum working voltage of the capacitor?

15. The design of a circuit requires a capacitor whose capacitance can be adjusted over a range of 10 to 100 microfarads. What general type of capacitor should be used in this circuit?

16. Fixed capacitors are classified according to the type of material used for the ______________________________.