

Answer to Essential Question 17.5: The net work you do to bring a charge Q from infinity to the center is $W_{You} = Q\Delta V = Q(V_f - V_i)$. V_i , the potential at infinity, is zero, so $W_{You} = QV_f$. This is zero if V_f , the potential at the center of the square from the four charges, is zero, which is true in cases 2 and 3. V_f is positive in case 1, so your net work in that case is negative if Q is negative. In case 4 V_f is negative, so your net work is negative if Q is positive. Negative work by you means that the fifth charge experiences a net attraction, and would accelerate unless you held it back.

17-6 Capacitors and Dielectrics

A capacitor is a device for storing charge. One example is a parallel-plate capacitor, consisting of two identical metal plates, each of area A , placed parallel to one another and separated by a distance d . The space between the plates is sometimes filled with insulating material. If it is we say that the capacitor contains a **dielectric**.

One way to charge a capacitor is to connect it to a battery, connecting one wire from the positive terminal of the battery to one plate of the capacitor, and a second wire from the negative terminal of the battery to the other plate. A diagram of this is shown in Figure 17.12, along with a circuit diagram. In the circuit diagram a capacitor is shown as two parallel lines of equal length, looking very much like a parallel-plate capacitor, and a battery is represented by two parallel lines of different length. The longer line on the battery symbol represents the positive terminal.

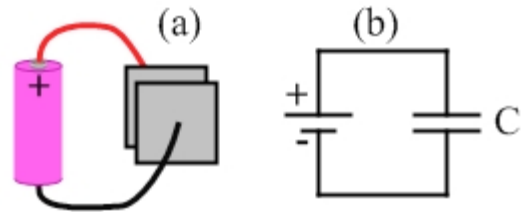


Figure 17.12: (a) A diagram, and (b) a circuit diagram, showing a battery connected to a capacitor (C) by two wires.

It is useful to think of the battery as a charge pump. The battery pumps electrons from the plate attached to the positive terminal, leaving that plate with a charge of $+Q$, to the plate attached to the negative terminal, giving that plate a charge of $-Q$. The capacitor then stores a charge Q . The battery pumps charge until the potential difference, ΔV , across the capacitor equals the potential difference across the battery. Another word for potential difference is voltage - the capacitor is charged when its voltage equals the battery voltage.

The charge Q stored in a capacitor is proportional to the capacitor's potential difference, ΔV :

$$Q = C \Delta V. \quad (\text{Eq. 17.6: Charge on a capacitor is proportional to its voltage})$$

where C is the capacitance of the capacitor, a measure of how much charge is stored for a particular voltage. The capacitance depends on the geometry of the capacitor, as well as on what, if anything, is between the plates of the capacitor. For a parallel-plate capacitor made of two plates of equal area A , separated by a distance d , the capacitance is given by:

$$C = \frac{\kappa \epsilon_0 A}{d}, \quad (\text{Eq. 17.7: Capacitance of a parallel-plate capacitor})$$

where κ is the dielectric constant of the material between the capacitor plates, and

$$\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \text{ C}^2 / (\text{N m}^2) \text{ is the permittivity of free space.}$$

The MKS unit for capacitance is the farad (F). $1 \text{ F} = 1 \text{ C/V}$.

A charged capacitor, with a charge $+Q$ on one plate and $-Q$ on the other, has an electric field directed from the positive plate to the negative plate. The field is uniform if the distance d between the plates is much smaller than the dimensions of the plate itself. In this case the magnitude of the field, E , is connected to, ΔV , the potential difference across the capacitor by:

$$E = \frac{|\Delta V|}{d}. \quad (\text{Eq. 17.8: Magnitude of the electric field in a parallel-plate capacitor})$$

Dielectrics.

A material in the space between capacitor plates is known as a **dielectric**. Usually this is an insulating material, because filling the space with a conductor would discharge the capacitor. It is interesting to review what happens with a conductor, however. As in Figure 17.13, when a conductor is placed in an external electric field the conduction electrons re-distribute themselves, giving an induced electric field E_{ind} inside the conductor equal in magnitude but opposite in direction to the external field. This gives a net field of zero inside the conductor.

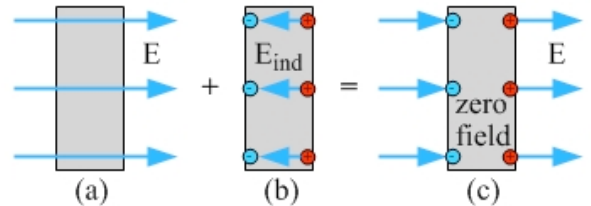


Figure 17.13: Conduction electrons distribute themselves so the field is zero inside a conductor.

The process is similar in an insulator. If the molecules in the insulator are unpolarized, the electric field polarizes them by shifting the electron clouds around the nuclei in the direction opposite to the external field; if the molecules are polarized to begin with, and randomly aligned as in Figure 17.14, the molecules experience a torque from the field that tends to align them with the field. In either case the positive and negative charges cancel one another in the bulk of the insulator, but there is a net positive charge along one face of the insulator and a net negative charge along the other face. This gives rise to an induced electric field E_{ind} inside the insulator that is opposite in direction to the external field. The induced field has a smaller magnitude than the external field, leading to a partial cancellation of fields inside the insulator, as in Figure 17.15.

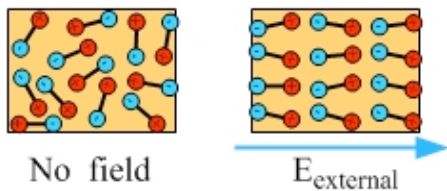


Figure 17.14: Polar molecules align with the field, when placed in an electric field.

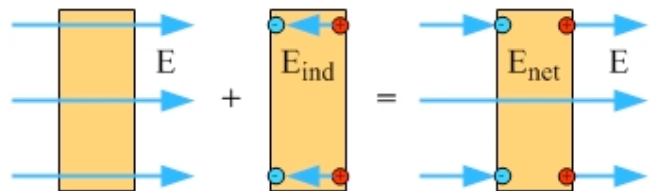


Figure 17.15: The induced field partly cancels the external field in the dielectric.

Related End-of-Chapter Exercises: 31, 61.

The dielectric constant of an insulator is the ratio of the external field to the net field inside the insulator:

$$\kappa = \frac{\bar{E}_0}{\bar{E}_{net}} \geq 1. \quad (\text{Eq. 17.9: The dielectric constant})$$

Selected dielectric constants are shown in Table 17.1.

Material	Dielectric constant
Vacuum	1.00000
Dry air	1.00056
Polystyrene	2.6
Mylar	3.1
Paper	3.6
Water	80

Table 17.1: Dielectric constants of various materials.

Essential Question 17.7: What is the dielectric constant of a conductor?