CONCEPTUAL EXAMPLE 17–7 **Potential energies.** Consider the three pairs of charges, Q_1 and Q_2, in Fig. 17–11. (*a*) Which set has a positive potential energy? (*b*) Which set has the most negative potential energy? (*c*) Which set requires the most work to separate the charges to infinity? Assume the charges all have the same magnitude.

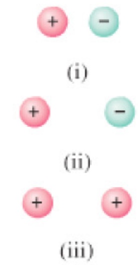

FIGURE 17–11 Example 17–7.

RESPONSE The potential energy equals the work required to bring the two charges near each other, starting at a great distance (∞). Assume the left (+) charge is already there. To bring a second charge close to the first from a great distance away (∞) requires work

$$W = Q_2 V_{\text{ba}} = k\frac{Q_1 Q_2}{r}$$

where r is the final distance between them. Thus the potential energy of the two charges is

$$\text{PE} = k\frac{Q_1 Q_2}{r}.$$

(*a*) Set (iii) has a positive potential energy because the charges have the same sign. (*b*) Set (i) has the most negative potential energy because the charges are of opposite sign and their separation is less than that for set (ii). That is, r is smaller for (i). (*c*) Set (i) will require the most work for separation to infinity. The more negative the potential energy, the more work required to separate the charges and bring the PE up to zero ($r = \infty$).

* 17–6 Potential Due to Electric Dipole; Dipole Moment

Two equal point charges Q, of opposite sign, separated by a distance l, are called an **electric dipole**. The electric field lines and equipotential surfaces for a dipole were shown in Fig. 17–7. Because electric dipoles occur often in physics, as well as in other fields such as molecular biology, it is useful to examine them more closely.

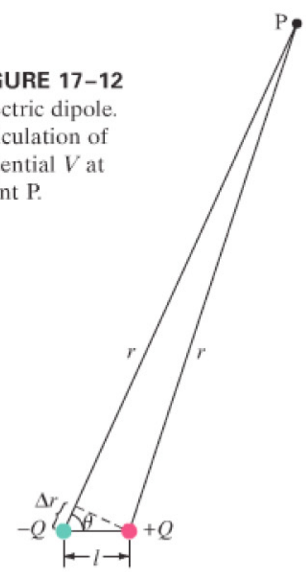

FIGURE 17–12 Electric dipole. Calculation of potential V at point P.

The electric potential at an arbitrary point P due to a dipole, Fig. 17–12, is the sum of the potentials due to each of the two charges:

$$V = \frac{kQ}{r} + \frac{k(-Q)}{r + \Delta r} = kQ\left(\frac{1}{r} - \frac{1}{r + \Delta r}\right) = kQ\frac{\Delta r}{r(r + \Delta r)},$$

where r is the distance from P to the positive charge and $r + \Delta r$ is the distance to the negative charge. This equation becomes simpler if we consider points P whose distance from the dipole is much larger than the separation of the two charges—that is, for $r \gg l$. From the diagram we see that $\Delta r \approx l\cos\theta$; since $r \gg \Delta r = l\cos\theta$, we can neglect Δr in the denominator as compared to r. Then we obtain

Potential far from a dipole

$$V \approx \frac{kQl\cos\theta}{r^2}. \qquad [\text{dipole; } r \gg l] \quad \textbf{(17–6a)}$$

We see that the potential decreases as the *square* of the distance from the dipole, whereas for a single point charge the potential decreases with the first power of the distance (Eq. 17–5). It is not surprising that the potential should fall off faster for a dipole; for when you are far from a dipole, the two equal but opposite charges appear so close together as to tend to neutralize each other.

Dipole moment $p = Ql$

The product Ql in Eq. 17–6a is referred to as the **dipole moment**, p, of the dipole. Equation 17–6a in terms of the dipole moment is

$$V \approx \frac{kp\cos\theta}{r^2}. \qquad [\text{dipole; } r \gg l] \quad \textbf{(17–6b)}$$

A dipole moment has units of coulomb-meters (C·m), although for molecules a smaller unit called a *debye* is sometimes used: 1 debye $= 3.33 \times 10^{-30}$ C·m.