

**Answer to Essential Question 17.2:** Because there is no net external force, the system's momentum is conserved. There is no initial momentum. For the net momentum to remain zero, the two momenta must always be equal-and-opposite. Defining right to be positive, and using 1 as a subscript for the ball on the left and 2 for the other ball, momentum conservation gives:

$$0 = -mv_1 + 3mv_2, \text{ which we can simplify to } v_1 = 3v_2.$$

$$\text{The energy conservation equation is: } +\frac{kq^2}{2.0 \text{ m}} = m(3v_2)^2 + 3mv_2^2 = 12mv_2^2$$

$$\text{This gives } v_2 = \sqrt{\frac{kq^2}{m(24.0 \text{ m})}}, \text{ and } v_1 = 3v_2 = 3\sqrt{\frac{kq^2}{m(24.0 \text{ m})}}.$$

$$\text{Using } m = 1.0 \text{ kg, we get } v_2 = 3.9 \times 10^{-2} \text{ m/s and } v_1 = 12 \times 10^{-2} \text{ m/s}.$$

### 17-3 Electric Potential

Gravitational potential,  $V_g$ , is related to gravitational potential energy in the same way that field is related to force, by a factor of the mass. Like field, gravitational potential is a way of measuring how an object with mass, or a set of objects with mass, influences the region around it.

The electric potential,  $V$ , at a particular point can be defined in terms of the electric potential energy,  $U$ , associated with an object of charge  $q$  being placed at that point:

$$V = \frac{U}{q}, \text{ or } U = qV. \quad (\text{Eq. 17.3: Connecting electric potential and potential energy})$$

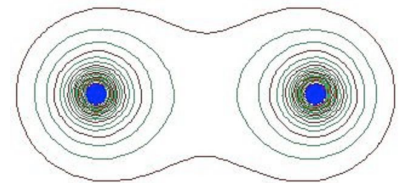
The unit for electric potential is the volt (V).  $1 \text{ V} = 1 \text{ J/C}$ .

A special case is the electric potential from a point charge with a charge  $Q$ :

$$V = \frac{kQ}{r}, \quad (\text{Equation 17.4: Electric potential from a point charge})$$

where  $r$  is the distance from the charge to the point in space where we are finding the potential. Electric potential is a scalar, so it has a sign but not a direction.

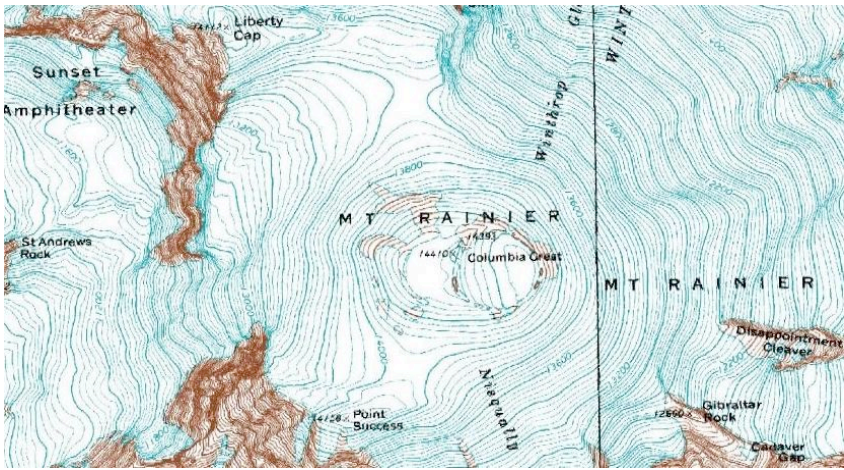
We can visualize potential by drawing **equipotentials**, lines or surfaces that connect points of the same potential. On a 2-D picture like Figure 17.4 equipotentials are lines; in a three-dimensional world we have equipotential surfaces. Around a point charge, for instance, the equipotential surfaces are spheres centered on the charge. As Figure 17.4 suggests, we can define a gravitational potential analogous to electric potential.



**Figure 17.4:** This diagram could represent the electric potential near two like charges, or the gravitational potential near two hills.

This is a little abstract, but you have probably seen gravitational equipotential lines, or contour lines, on a topographical map, as in Figure 17.5. Contour lines connect points at the same height – such points have the same gravitational potential. Where the lines are close together the terrain is steep; where the lines are far apart the terrain is flatter. If you want to go for an easy hike you have two choices. You can stick to flat terrain where the contour lines are far apart, or you can walk along a trail along a contour line, where the height is constant.

**Figure 17.5:** Contour lines on a topographical map, showing the terrain around the summit of Mt. Rainier, in Washington State. Photo credit: NASA/USGS.



Moving along a contour line requires no work, while moving from one contour line to another does involve work, because the gravitational potential energy changes. Equipotential lines give us the same information. Moving a charged object at constant speed from one place to another along an equipotential requires no work; but moving from one equipotential to another does involve work. Note that equipotential lines are always perpendicular to field lines, and the field points in the direction of decreasing potential.

**Potential in a Uniform Field**

In a uniform field, we can define the zero for potential to be anywhere we find to be convenient. The value of the potential at a particular point is not what is important. What is of primary importance is how the potential changes from one point to another. In a uniform electric field we define the potential difference (the difference in potential between two points) as:

$$\Delta V = -E \Delta r \cos \theta , \quad \text{(Equation 17.5: Potential difference in a uniform field)}$$

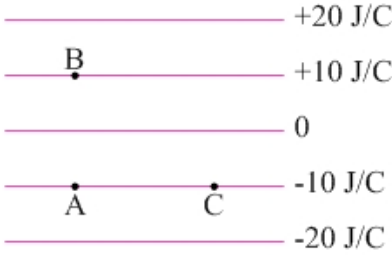
where  $\theta$  is the angle between the electric field  $\vec{E}$  and the displacement  $\Delta \vec{r}$ .

Electric potential has units of volts, or J/C. We see that the electric potential difference between points A and B in Figure 17.6 is +20 J/C (starting at A and going to B), and between points C and B (starting at C and going to B) it is also +20 J/C. If we move an object that has a charge of +2 mC from A to B, or from C to B, what is the change in electric potential energy? This equals the work we do to move the object, assuming its kinetic energy remains the same.

$$\Delta U = q \Delta V = q (V_B - V_A) = 2 \text{ mC} (+10 \text{ J/C} - (-10 \text{ J/C})) = 2 \text{ mC} \times (+20 \text{ J/C}) = +40 \text{ mJ} .$$

Moving the 2 mC object from C to B also produces a +40 mJ change in potential energy; in moving it from A to C there is no change in potential energy (and no work), and moving it from B to either A or C changes the potential energy by -40 mJ.

If we change objects, using an object with a charge of +5 mC, for instance, the change in potential energy is easy to find. It is simply the new charge multiplied by the change in potential.



**Related End-of-Chapter Exercises: Problems 13, 14, 36, 43.**

**Essential Question 17.3:** If we moved an object with a charge of -2 mC from point A to point B in Figure 17.6, is the change in potential energy still +40 mJ? Explain.

**Figure 17.6:** Equally spaced equipotentials are a hallmark of a uniform field. Field points in the direction of decreasing potential, so the field is directed down in this case.