Answer to Essential Question 6.5: The two objects experience equal forces over equal displacements, so the work done is the same. Thus, the change in kinetic energy is the same for each and, because they start with no kinetic energy, **their final kinetic energies are equal.**

The change in momentum is the force multiplied by the time over which the force acts. Both objects experience the same force, but, because B has more mass, B takes more time to move through the distance d than A does. The force acts on B for a longer time, so ***B*'s final momentum is larger than *A*'s**. **Related End-of-Chapter Exercises: 9, 10, 52 – 54.**

6-6 Conservative Forces and Potential Energy

Let's first write down a method for solving a problem involving work and kinetic energy, similar to the method we use for solving an impulse-and-momentum problem.

A General Method for Solving a Problem Involving Work and Kinetic Energy

1. Draw a diagram of the situation.
2. Add a coordinate system to the diagram, showing the positive direction(s). Doing so helps remind us that force and displacement are vector quantities.
3. Organize what you know, perhaps by drawing a free-body diagram of the object, or drawing a graph of the net force as a function of position.
4. Apply Equation 6.8 $\left(F_{net}\, \Delta r \cos\theta = \Delta K\right)$ to solve the problem.

We now have the tools needed to investigate some intriguing ideas about energy.

EXPLORATION 6.6A – Making gravity work

Step 1 - ***Take a ball of weight mg = 10 N and move it through a distance of 2 m. How much work does gravity do on the ball during the motion?*** It is tempting to multiply 10 N by 2 m to get 20 J and say that's the work, but the work depends on the angle between the force and the displacement (see Equation 6.7, $W = F_{net} \Delta r \cos\theta$). The direction of the displacement was not given, so we can't say how much work is done.

Let's consider the extreme cases. If we move the ball up 2 m, the force of gravity and the displacement are in opposite directions, so the work done is –20 J. If we move it down 2 m, the force and displacement are in the same direction, so the work done is +20 J. So, the work done is somewhere between –20 J and + 20 J. Work can even be zero, if the displacement is horizontal.

Step 2 – ***What is the work done by gravity, if we give our 10 N ball a displacement of 2 m down at the same time we displace it 4 m horizontally?*** Gravity still does +20 J of work. All we have to worry about is the vertical motion. There is no work done by gravity for the horizontal motion.

Step 3 - ***Does the path followed make any difference?*** In Figure 6.15, point B is 2 m below, and 4 m horizontally, from A. For any path starting at A and ending at B, the work done by gravity in moving a 10-N ball is +20 J. The horizontal motion does not matter. What matters is that every path involves the same net 2 m vertical downward displacement.

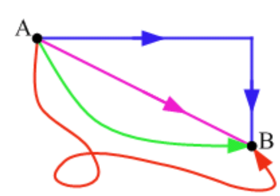

Figure 6.15: The work done by gravity, when an object is moved from point A to point B, is the same no matter what path the object is moved along.

Key idea: The work done by gravity on an object is ***path-independent***. All that matters is the position of the initial point and the position of the final point. It doesn't matter how the object gets from the initial point to the final point. **Related End-of-Chapter Exercise: 43.**

When the work done by a force is path-independent, we say the force is **conservative**. Gravity is a conservative force, and we will discuss other examples later in the book. Other conservative forces include the spring force (chapter 12) and the electrostatic force (chapter 16).

Instead of talking about the work done by a conservative force, we usually do something equivalent and talk about the change in **potential energy** associated with the force. Potential energy can, in general, be thought of as energy something has because of its position.

At the surface of the Earth, where we take the force of gravity to be constant, the work done by gravity is $W_g = -mg\Delta y$. The change in gravitational potential energy, ΔU_g, has the opposite sign: $\Delta U_g = -W_g = mg\Delta y$. (Eq. 6.9: **Change in gravitational potential energy**)

> When the force of gravity is constant, we define **gravitational potential energy** as
>
> $U_g = mgh$, (Equation 6.10: **Gravitational potential energy**)
>
> where h is the height that the object is above some reference level. We can choose any convenient level to be the reference level.

EXPLORATION 6.6B – Talking about potential energy

A 10-N ball is moved by some path from *A* to *B*, where *B* is 2 m lower than *A*. What is the ball's initial gravitational potential energy? What is its final gravitational potential energy? What is the change in the gravitational potential energy? Analyze the following conversation.

Bob: "We can use Equation 6.9 to find the change in gravitational potential energy. Because *B* is 2 meters lower than *A*, the Δy in the equation is –2 meters. Multiplying this by an *mg* of 10 newtons gives a change in gravitational potential energy of –20 joules."

Andrea: "If I define *B* as the level where the potential energy equals zero, then the ball's potential energy at *A* is +20 joules. The ball's potential energy changes from +20 joules to zero for a change of –20 joules."

Bob: "I agree with what you get for the change but we have to define the zero for potential energy at *A*. That gives the object a potential energy of –20 joules at *B*."

Christy: "We can each pick our own zero. It doesn't make any difference. No matter where you put the zero you get –20 joules for the change in potential energy."

Which student is correct?

Bob's first statement is correct. Andrea is correct, and so is Christy. Christy makes an important point – everyone agrees on the value of the change in potential energy, no matter which level they choose as the zero. In his second statement, Bob is incorrect about having to set the potential energy to be zero at *A*. You can do that, but, as Christy points out, you don't have to.

> **Key idea**: The change in potential energy, which everyone agrees on, is far more important than the actual value of the potential energy. **Related End-of-Chapter Exercise: 12.**

Essential Question 6.6: We often use terminology like "the ball's gravitational potential energy." Does the ball really have gravitational potential energy all by itself?