GRAVITATIONAL POTENTIAL ENERGY

LEARNING OUTCOMES:

- Explain gravitational potential energy in terms of work done against gravity.
- Show that the gravitational potential energy of an object of mass m at height h on Earth is given by $\mathrm{PE_g} = mgh$.
- Show how knowledge of the potential energy as a function of position can be used to simplify calculations and explain physical phenomena.

Work Done Against Gravity

Climbing stairs and lifting objects is work in both the scientific and everyday sense—it is work done against the gravitational force. When there is work, there is a transformation of energy. The work done against the gravitational force goes into an important form of stored energy that we will explore in this section.

Let us calculate the work done in lifting an object of mass m through a height h, such as in Figure 1. If the object is lifted straight up at constant speed, then the force needed to lift it is equal to its weight mg. The work done on the mass is then $W = Fd = mgh$. We define this to be the **gravitational potential energy** $(\mathrm{PE_g})$ put into (or gained by) the object-Earth system. This energy is associated with the state of separation between two objects that attract each other by the gravitational force. For convenience, we refer to this as the $\mathrm{PE_g}$

gained by the object, recognizing that this is energy stored in the gravitational field of Earth. Why do we use the word "system"? Potential energy is a property of a system rather than of a single object—due to its physical position. An object's gravitational potential is due to its position relative to the surroundings within the Earth-object system. The force applied to the object is an external force, from outside the system. When it does positive work it increases the gravitational potential energy of the system. Because gravitational potential energy depends on relative position, we need a reference level at which to set the potential energy equal to 0. We usually choose this point to be Earth's surface, but this point is arbitrary; what is important is the *difference* in gravitational potential energy, because this difference is what relates to the work done. The difference in gravitational potential energy of an object (in the Earth-object system) between two rungs of a ladder will be the same for the first two rungs as for the last two rungs.

Converting Between Potential Energy and Kinetic Energy

Gravitational potential energy may be converted to other forms of energy, such as kinetic energy. If we release the mass, gravitational force will do an amount of work equal to mgh on it, thereby increasing its kinetic energy by that same amount (by the work-energy theorem). We will find it more useful to consider just the conversion of $\mathrm{PE_g}$ to KE without explicitly considering the intermediate step of work. (See Example 2.) This shortcut makes it is easier to solve problems using energy (if possible) rather than explicitly using forces.
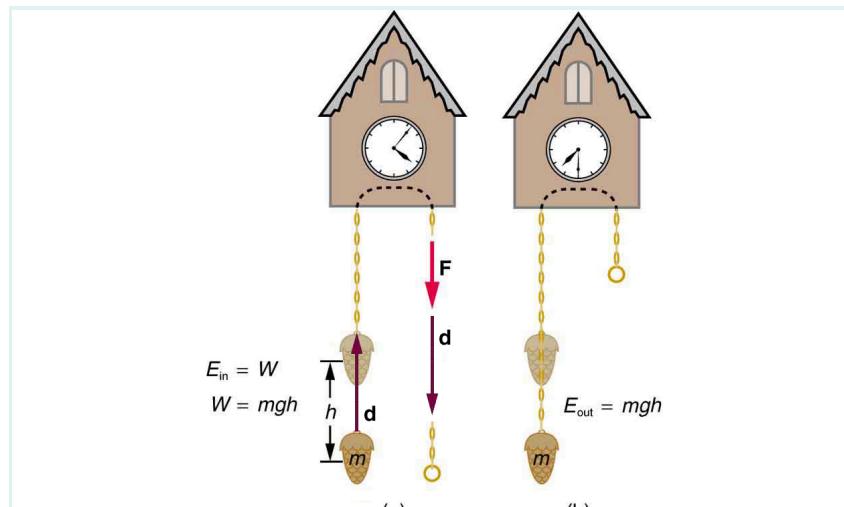

Figure 1: *(a) The work done to lift the weight is stored in the mass-Earth system as gravitational potential energy. (b) As the weight moves downward, this gravitational potential energy is transferred to the cuckoo clock.*

More precisely, we define the *change* in gravitational potential energy

\Delta \PE_{\text{g}} $to be

ΔPE_g $
= mgh,$</div> where, for simplicity, we denote the change in height by h rather than the usual Δh. Note that h is positive when the final height is greater than the initial height, and vice versa. For example, if a 0.500-kg mass hung from a cuckoo clock is raised 1.00 m, then its change in gravitational potential energy is

Note that the units of gravitational potential energy turn out to be joules, the same as for work and other forms of energy. As the clock runs, the mass is lowered. We can think of the mass as gradually giving up its 4.90 J of gravitational potential energy, *without directly considering the force of gravity that does the work.*

The equation $\Delta PE\_g = mgh$ applies for any path that has a change in height of h, not just when the mass is lifted straight up. (See Figure 2.) It is much easier to calculate mgh (a simple multiplication) than it is to calculate the work done along a complicated path. The idea of gravitational potential energy has the double advantage that it is very broadly applicable and it makes calculations easier. From now on, we will consider that any change in vertical position h of a mass m is accompanied by a change in gravitational potential energy mgh, and we will avoid the equivalent but more difficult task of calculating work done by or against the gravitational force.
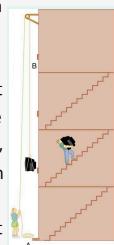
Figure 2:
The change in gravitational potential energy $\$(\Delta PE_\text{g}\$$ $\)$ between points A and B is independent of the path. $\(\Delta PE_\text{g} =mgh \)$ for any path between the two points. Gravity is one of a small class of forces where the work done by or against the force depends only on the starting and ending points, not on the path between them.

A 60.0-kg person jumps on
3.00 m. If he lands stiffly (wit
by 0.500 cm), calculate th

Stra

This person's energy is broug
the work done on him by the
PE_g is transformed into KE a
the floor reduces this

Solu

The work done on the pers
give

$$W = Fd\cos\theta$$

with a minus sign because the
and the force from floor
$(\cos\theta = \cos 180° = -1)$. The flo
system, so it doe

The kinetic energy the person
is the amount of potential e
heig

$$KE = -\Delta PE_g$$

The distance d that the pe
smaller than the height h of
change in gravitational pote
bend is

The work W done by the flo
person and brings the pers

$$W = -KE =$$

Combining this equation wit

$$-Fd = m$$

Recalling that h is negative b
the force on the kn

$$F = -\frac{mgh}{d} = -\frac{(60.0\text{kg})\left(9.80\text{m}}{5.00\times 1}$$

Discu

Such a large force (500 tim
weight) over the short imp
bones. A much better way
bending the legs or rolling o
time over which the force act

Eq. (2)

Using Potential Energy to Simplify Calculations

this way yields a force 100
example. A kangaroo's hop
action. The kangaroo is th
hopping for locomotion, b
cushioned by the bending o
See Fig

Eq. (2)

$$mgh = (0.500\text{kg})\left(9.80\text{m/s}^2\right)(1.00\text{m})$$
$$mgh = 4.90\text{kg}\cdot\text{m}^2/\text{s}^2 = 4.90\text{J}.$$