

Class 15

Quiz on Wednesday. Sec 202 will meet in Pasteur 301, around the corner from the Tutoring center in Southwick

Wed. Clicker Question.

Kinetic Energy and the Work-Energy Principle

The definition of Energy

Energy is different from all other concepts in physics in that there is no *single* definition for it. Instead there are many different kinds of energy.

Kinetic Energy

Kinetic energy is energy associated with *motion*.

If we use Newton's laws to compute the work done in accelerating an object, over a certain distance, it turns out that the work is

$$W_{net} = \frac{1}{2} m v_2^2 - \frac{1}{2} m v_1^2$$

If we define *kinetic energy* as

$$KE = \frac{1}{2} m v^2$$

the result is the **work-energy principle**

The work done in changing the state of motion of an object is equal to the change in the kinetic energy.

$$W_{net} = KE_2 - KE_1 = \Delta KE$$

This relationship is not anything which is not contained in Newton's laws, it is a restatement in terms of energy, and make many problems much easier to solve.

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Potential Energy

While Kinetic energy is associated with motion *potential energy* is associated with *position*.

Whereas kinetic energy has an obvious zero, when the velocity is zero, potential energy is only defined as a *change*.

Potential energy itself has come in different kinds.

Gravitational Potential Energy

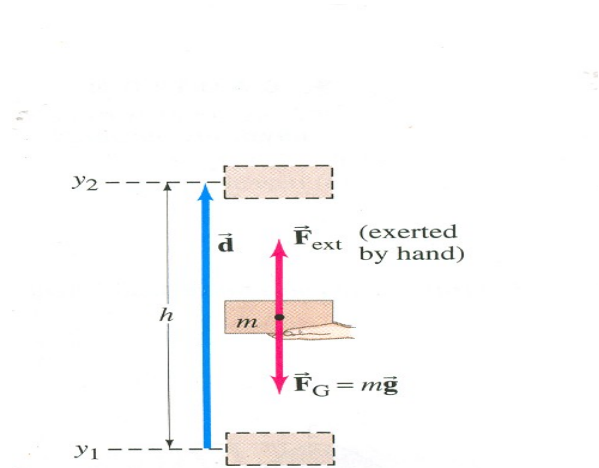


FIGURE 6-11 A person exerts an upward force $F_{\text{ext}} = mg$ to lift a brick from y_1 to y_2 .

As with kinetic energy we start with the net work done when we lift an object, without any acceleration.

If we calculate the work done by an external force in lifting the object shown above we get

$$W_{\text{ext}} = F_{\text{ext}} d \cos(0) = mg * (y_2 - y_1) \quad (6.)$$

We can also compute the work done by gravity in the same process.

$$W_G = F_G d \cos(180) = mg * (-1)(y_2 - y_1) = -mg(y_2 - y_1)$$

Note that the *net* or *total* work done is zero. This accords with the *work-energy* principle since we have specified that there is no acceleration during the lifting, so there is no change in kinetic energy.

Now let's think about what happens if, after lifting the object to a height $h = y_2 - y_1$, we let the object fall.

From our kinetic relationships we have

$$v_f^2 = v_i^2 + 2gh$$

Since we drop the object the initial velocity is zero so we have

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$$v_f^2 = 2 g h$$

To see how this relates to energy we multiply both sides of the above equation by $\frac{1}{2}m$ we get

$$\frac{1}{2} m v_f^2 = \frac{1}{2} m (2 g h)$$

$$\frac{1}{2} m v_f^2 = m g h$$

This means that the object has acquired a *kinetic* energy equal to $m g h$.

Because we can object to a height h , and then drop it and have it acquire a kinetic energy equal to $m g h$ we call the quantity $m g h$ **gravitational potential energy**.

It is *potential* energy, because it can be turned into *actual* kinetic energy.

Potential energy is only meaningfully defined as a *change* when an object moves from one position to another.

$$\Delta PE_{\text{Grav}} = m g (y_2 - y_1) = m g h$$

Work and potential energy

If we look at equation (6.)

$$W_{\text{ext}} = m g (y_2 - y_1)$$

so, combining this with the equation above it gives

$$W_{\text{ext}} = \Delta PE$$

The work done by the external force is equal to the change in potential energy

We can also consider the work done by the gravitation force in the lifting process.

$$W_{\text{Grav}} = F_{\text{ext}} d \cos(180) = (-1) * m g * (y_2 - y_1)$$

$$W_{\text{Grav}} = -m g (y_2 - y_1)$$

$$W_{\text{Grav}} = -\Delta PE$$

Potential energy is an aspect of a *system* not of an isolated object. In order for there to be a defined change in potential energy, there must be a force, and so there must be a second object to exert that force.

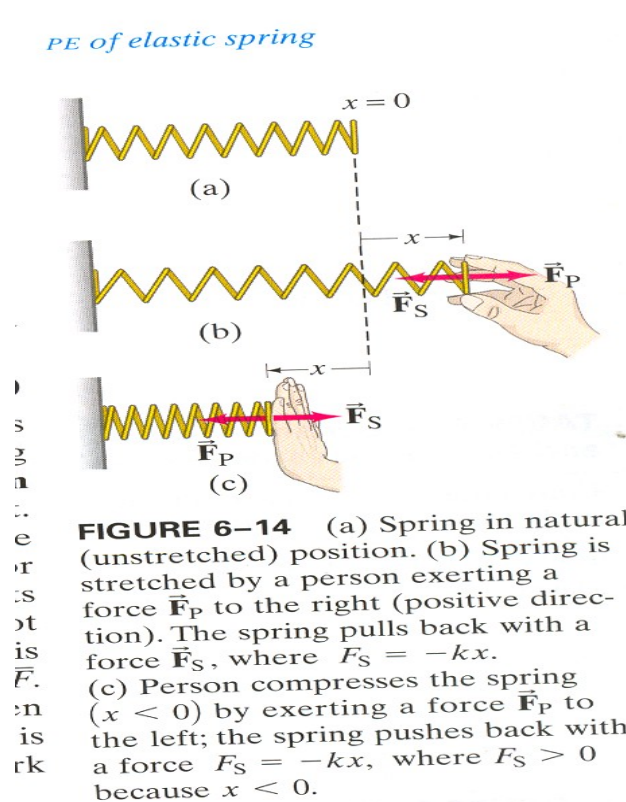
A change in potential energy associated with a force, e. g. gravity, is the *negative* of the work done by that force.

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Elastic Potential Energy

To see how this works with a force other than gravity, let's consider the force exerted by a spring.

Springs have a range of stretching or compressing in which the force needed is proportional to the amount of stretch or compression.



In this case the force is not constant, so the work is computed from the area under the force vs distance function, as we did with varying velocity.

The result is that the work done in compressing a spring a distance x from the spring's equilibrium position is given by

$$W_{sp} = \frac{1}{2} k x^2$$

If we apply the principle that the work done by a against a force gives us the potential energy stored we have that

$$W_{El} = \frac{1}{2} k x^2$$

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Conservative and Non-Conservative Forces

The 2 forces which we have so far calculated the potential energy for the gravitational force and for a spring force.

These 2 forces are examples of *conservative* forces.

Independence of the path ---- In a system in which the force is *conservative* the work done is stored as potential energy.

The amount of work done does not depend on the path take by the object being pushed. For example if I carry a mass up a ramp to a height h , or if I lift the object directly to that height, the work done, and hence the potential energy is still given by

$$W_{\text{Grav}} = m g h$$

Friction, a non-conservative force

The independence of path is clearly *not* the case, when friction is the force we doing work against.

I can push a box around a 3 sides of a square path on a surface with friction and end up at the same place I started. On each leg, L , of the path I have done work. So the work I have done is

$$W = 3F_{fr} L$$

Alternatively I can slide the box across one leg of the square and get to the same place. In this case the work I have done is

$$W = F_{fr} L$$

If the work we do, in getting from one point to another depends on the path we take, we are dealing with a non-conservative force.

Non-conservative force do NOT store potential energy

When I do work against a conservative force, like lifting an object, I can then drop the object and the work I have done will be turned into kinetic energy as the object falls.

When I do work against friction, and then let go of the object, nothing happens. There has been no stored potential energy.

The work-energy principle extended to include non-conservative forces

Earlier we stated that the *net* work, done on an object is equal to the change in kinetic energy.

$$W_{\text{net}} = KE_2 - KE_1 = \Delta KE$$

If non conservative forces are involved then we need to divide the work done into a part done by the conservative forces and the work done by non-conservative forces.

$$W_c + W_{\text{NC}} = \Delta KE$$

If we rearrange this we get

$$W_{\text{NC}} = \Delta KE - W_c$$

The work done by a conservative force such as gravity we have seen above as

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$$W_{\text{Grav}} = -\Delta PE$$

If we put this into the formula above it we get

$$W_{\text{NC}} = \Delta KE + \Delta PE$$

Mechanical Energy and its Conservation

If we consider the above equation in the case in which there is *no non-conservative* work then we get

$$\Delta KE + \Delta PE = 0$$

If we define *mechanical energy* as $\Delta KE + \Delta PE$, then we see that, in the absence of any non-conservative force, the change in mechanical energy is zero, so **mechanical energy is conserved.**