

Work and Energy

Physics 1425 Lecture 12

What is Work and What Isn't?

- In physics, **work has a very restricted meaning!**
- *Doing homework isn't work.*
- **Carrying somebody a mile on a level road isn't work...**
- **Lifting a stick of butter three feet *is* work—in fact, about one unit of work.**

Work is *only* done by a *force*...

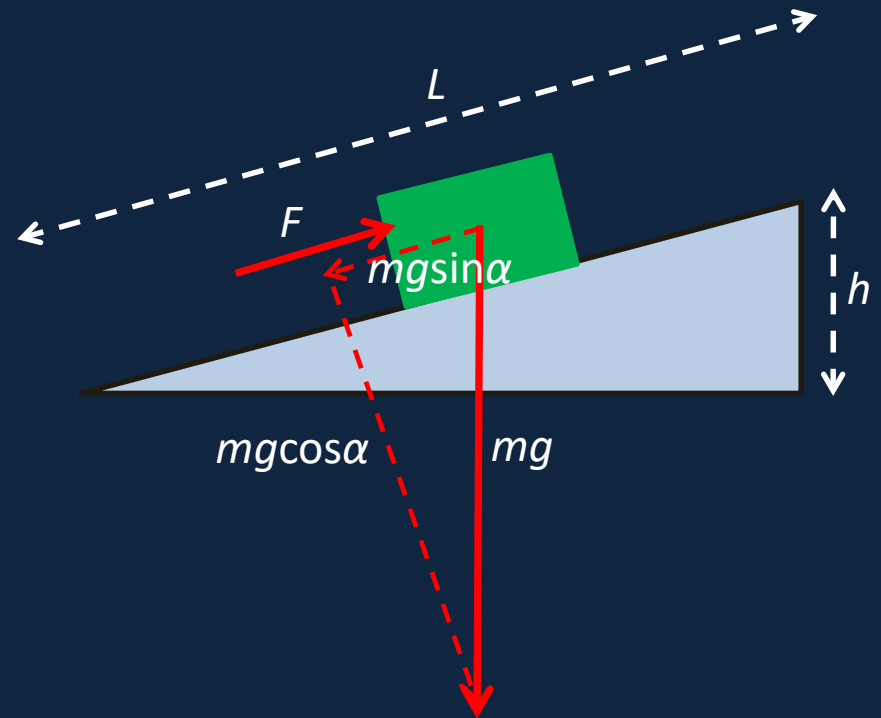
- and, the force **has to move something!**
- Suppose I lift one kilogram up one meter...
- I do it at a slow steady speed—my force just balances its weight, let's say 10 Newtons.
- **Definition:** *if I push with 1 Newton through 1 meter, I do work 1 Joule.*
- So lifting that kilogram took 10 Joules of work.

Only motion *in the direction of the force* counts ...

- Carrying the weight straight across the room at constant height does **no work** on the weight.
- After all, it could have been just sliding across on ice—and the ice does no work!
- What about pushing a box at constant velocity up a frictionless slope?

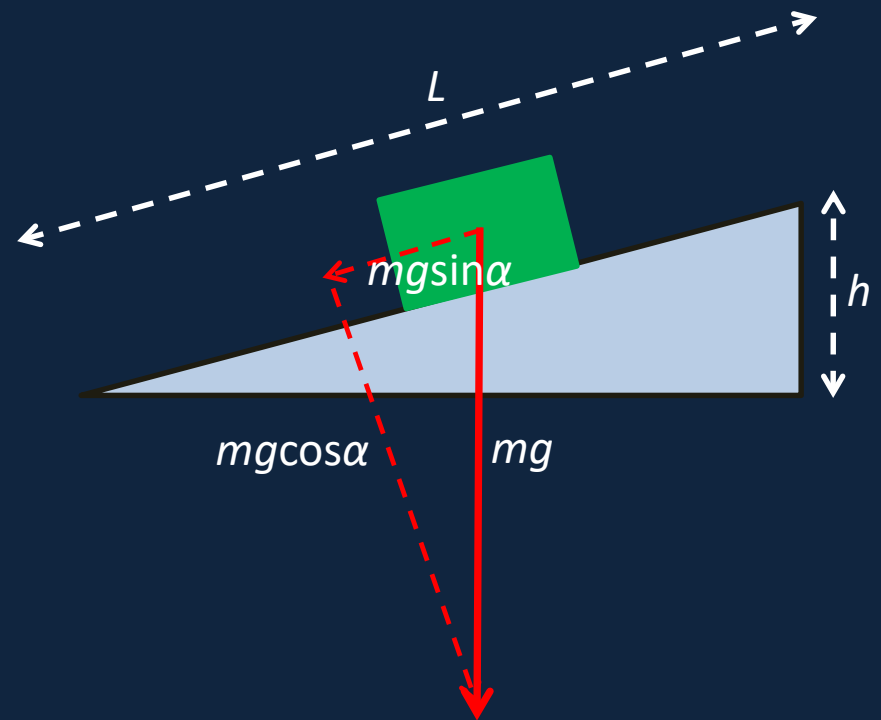
Pushing a box up a frictionless slope...

- Suppose we push a box of mass m at a steady speed a distance L up a frictionless slope of angle α .
- The **work done** is $FL = mgL\sin\alpha = mgh$ where h is the height gained.
- **Meanwhile, gravity is doing *negative work*... its force is directed *opposite to the motion*.**



...and letting it slide back down.

- Letting the box go at the top, the force of gravity along the slope, $mgL\sin\alpha$, will do **exactly** as much work on the box on the way down as we did pushing it up.
- Evidently, the work we did raising the box was *stored* by gravity.
- This “stored work” is called **potential energy** and is written $U = mgh$



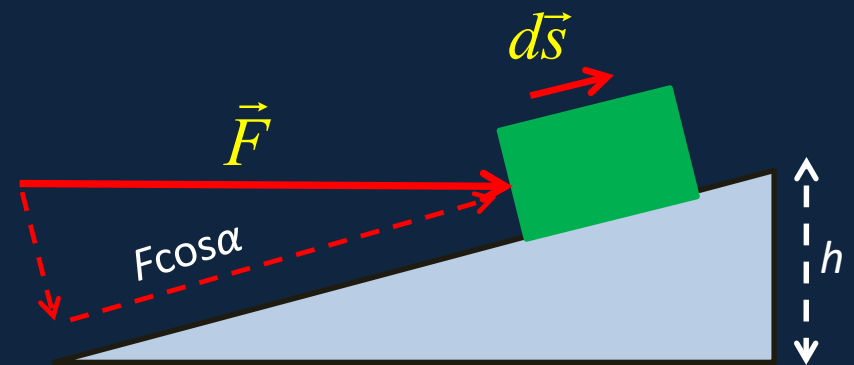
Energy is the Ability to Do Work

- We've established that pushing the box up a frictionless slope against gravity stores—in gravity—the ability to do work on the box on its way back down.
- This “stored work” is called **potential energy**.
- Notice it **depends** *not* on the slope, but **only** on the net height gained:

$$U = mgh.$$

What if you push the box *horizontally*?

- The box only moves up the slope, so **only the component of force in that direction does any work.**
- If the box moves a small distance ds , the work done
 - $dW = (F\cos\alpha)ds.$
 - This vector combination comes up a lot: we give it a special name... $dW = \vec{F} \cdot d\vec{s}$



The Vector Dot Product $\vec{A} \cdot \vec{B}$

- The **dot product** of two vectors is defined by:

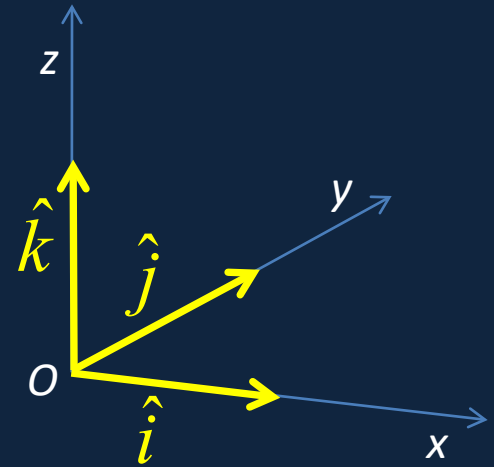
$$\vec{A} \cdot \vec{B} = AB \cos \theta$$

where A , B are the lengths of the vectors, and θ is the angle between them.

- **Alternately:** The dot product is the length of \vec{A} multiplied by the **length of the component of \vec{B} in the direction of \vec{A}** .
- From this $\vec{A} \cdot (\vec{B} + \vec{C}) = \vec{A} \cdot \vec{B} + \vec{A} \cdot \vec{C}$.
- If the vectors are **perpendicular**, $\vec{A} \cdot \vec{B} = 0$.

Dot Product in Components

- Recall we introduced three orthogonal unit vectors $\hat{i}, \hat{j}, \hat{k}$ pointing in the directions of the x, y and z axes respectively.
- Note $\hat{i} \cdot \hat{i} = \hat{i}^2 = 1, \hat{i} \cdot \hat{j} = \hat{j} \cdot \hat{k} = \hat{k} \cdot \hat{i} = 0$.
- Writing $\vec{A} = A_x \hat{i} + A_y \hat{j} + A_z \hat{k}$ we find

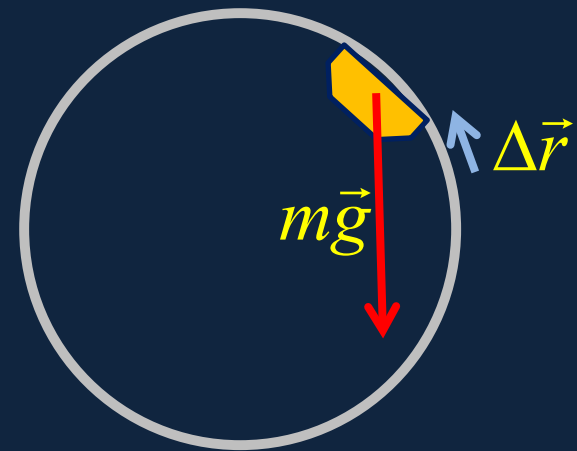


$$\vec{A} \cdot \vec{B} = A_x B_x + A_y B_y + A_z B_z.$$

Positive and Negative Work

- As the loop the loop car climbs a small distance $\Delta\vec{r}$, the force of gravity $m\vec{g}$ does work $\vec{F} \cdot \vec{d} = m\vec{g} \cdot \Delta\vec{r}$. This is **negative** on the way up—the angle between the two vectors is more than 90° .
- Total work around part of the loop can be written

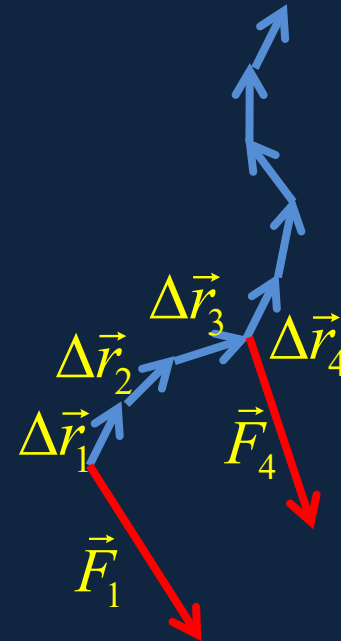
$$W = \sum \vec{F} \cdot \Delta\vec{r} = \int_{\vec{a}}^{\vec{b}} \vec{F} \cdot d\vec{r}$$



Work done by any Force along any Path

- The expression for work done along a path is **general**: just break the path into small pieces, add the work for each piece, then go to the limit of tinier pieces to give an integral:

$$W = \sum_i \vec{F}_i \cdot \Delta\vec{r}_i = \int_{\vec{a}}^{\vec{b}} \vec{F} \cdot d\vec{r}$$



In components:

$$W = \int_{a_x}^{b_x} F_x dx + \int_{a_y}^{b_y} F_y dy + \int_{a_z}^{b_z} F_z dz$$

Force of a Stretched Spring

- If a spring is pulled to extend beyond its natural length by a distance x , it will pull back with a force

$$F = -kx$$

where k is called the “spring constant”.

The same linear force is also generated when the spring is *compressed*.

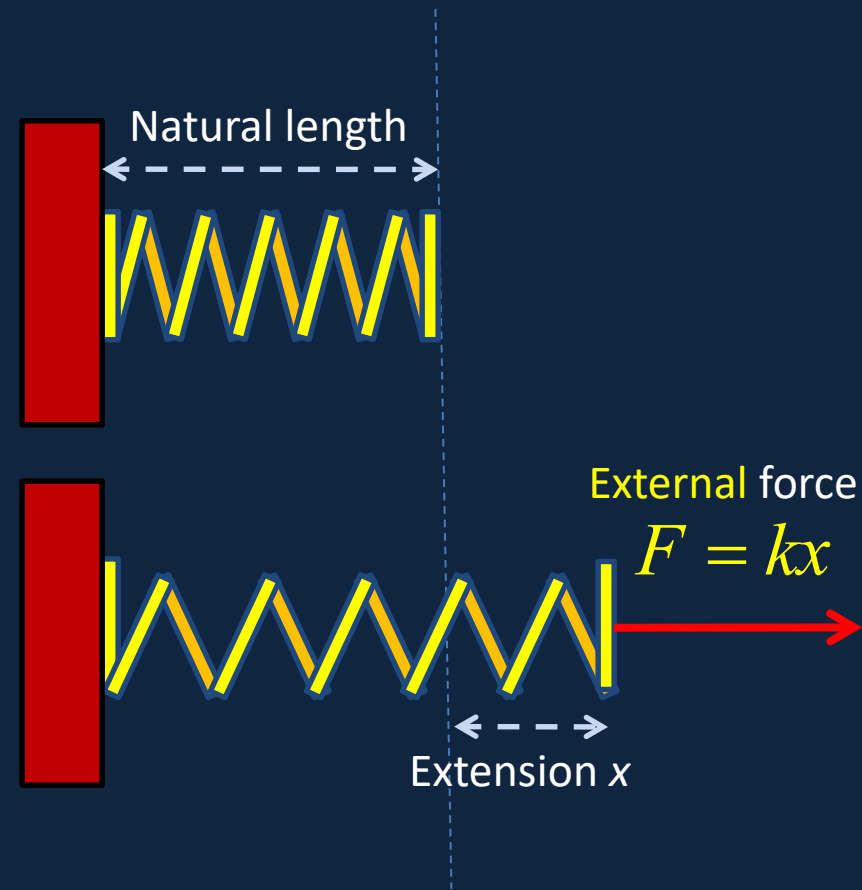


Work done in *Stretching* a Spring

- The work from an **external** force needed to stretch the spring from x to $x + \Delta x$ is $kx\Delta x$, so the **total** work to stretch from the natural length to an extension x_0

$$W = \int_0^{x_0} kx dx = \frac{1}{2} kx_0^2.$$

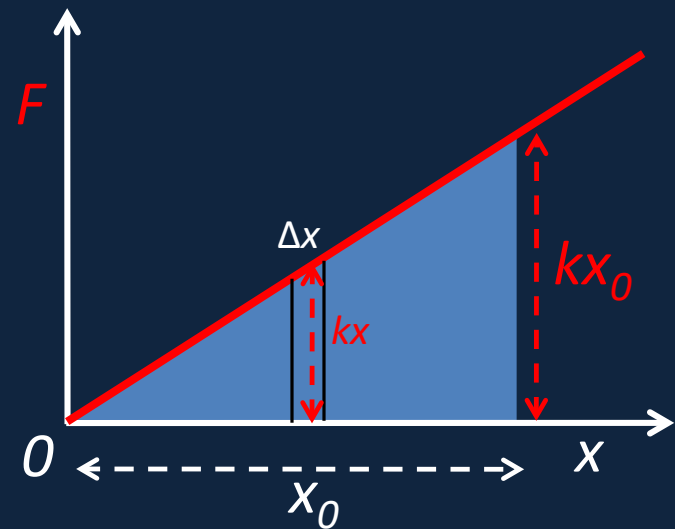
This work is stored by the spring as **potential energy**.



Total Work as *Area Under Curve*

- Plotting a graph of external force $F = kx$ as a function of x , the work to stretch the spring from x to $x + \Delta x$ is $kx\Delta x$, just the *incremental area under the curve*, so the **total** work is the **total** area

$$W = \int_0^{x_0} kx dx = \frac{1}{2} kx_0^2$$



Area under this “curve” = $\frac{1}{2}$ base \times height = $\frac{1}{2} kx_0^2$
In fact, the total work done is the area under the force/distance curve for *any* curve: it’s a sum of little areas $F\Delta x$ corresponding to work for Δx .