More Energy Topics

Physics 1425 Lecture 14

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Topics for Today

- Overall Energy Conservation
- Gravitation and Escape Velocity
- Power
- Equilibrium

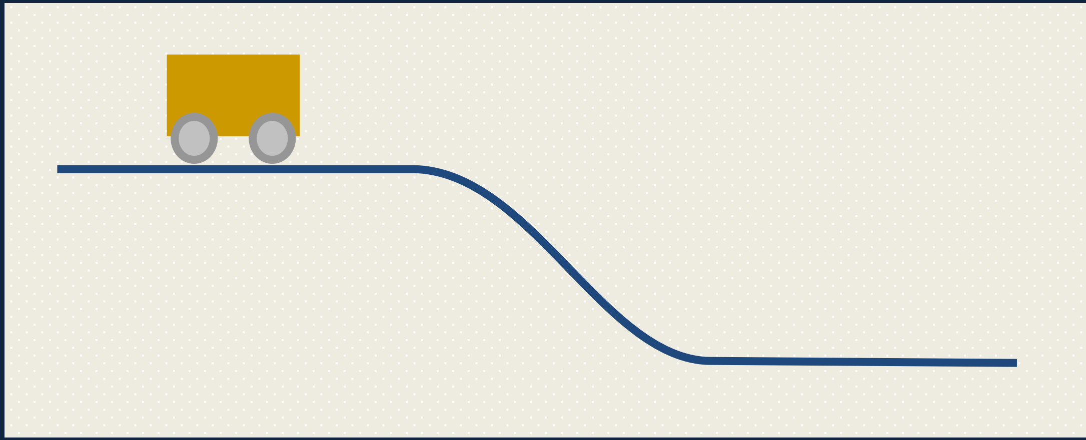
Overall Energy Conservation

- In the real world, there's lots of friction, air resistance, etc., so even for a well-designed roller coaster, $mgh + \frac{1}{2}mv^2$ gradually goes down.
- Experimentally, loss of mechanical energy is invariably accompanied by the production of heat: and the amount of heat produced, properly measured, equals the mechanical energy lost.

ConcepTest 8.9 Cart on a Hill

A cart starting from rest rolls down a hill and at the bottom has a speed of 4 m/s. If the cart were given an initial push, so its initial speed at the top of the hill was 3 m/s, what would be its speed at the bottom?

1) 4 m/s
2) 5 m/s
3) 6 m/s
4) 7 m/s
5) 25 m/s



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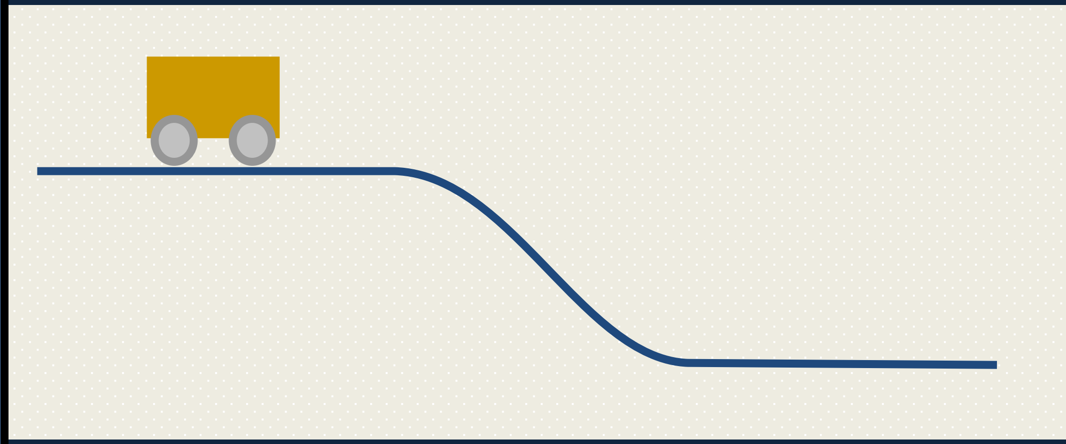
When starting from rest, the cart's PE is changed into KE:

$$\Delta PE = \Delta KE = \frac{1}{2}m(4)^2$$

When starting from 3 m/s, the final KE is:

$$KE_f = KE_i + \Delta KE$$
$$= \frac{1}{2}m(3)^2 + \frac{1}{2}m(4)^2$$
$$= \frac{1}{2}m(25)$$
$$= \frac{1}{2}m(5)^2$$



Speed is not the same as kinetic energy

ConcepTest 8.10a Falling Leaves

You see a leaf falling to the ground with *constant speed*. When you first notice it, the leaf has initial total energy $PE_i + KE_i$. You watch the leaf until just before it hits the ground, at which point it has final total energy $PE_f + KE_f$. How do these total energies compare?

1) $PE_i + KE_i > PE_f + KE_f$
2) $PE_i + KE_i = PE_f + KE_f$
3) $PE_i + KE_i < PE_f + KE_f$
4) impossible to tell from the information provided

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As the leaf falls, **air resistance exerts a force on it opposite to its direction of motion**. This **force does negative work**, which prevents the leaf from accelerating. This frictional force is a nonconservative force, so the **leaf loses energy as it falls**, and its **final total energy is less than its initial total energy**.

Follow-up: What happens to leaf's KE as it falls? What net work is done?

ConcepTest 8.10b Falling Balls

You throw a ball straight up into the air. In addition to *gravity*, the ball feels a force due to *air resistance*. Compared to the time it takes the ball to go up, the time it takes to come back down is:

1) smaller
2) the same
3) greater

ConcepTest 8.10b Falling Balls

You throw a ball straight up into the air. In addition to ***gravity***, the ball feels a force due to ***air resistance***. Compared to the time it takes the ball to go up, the time it takes to come back down is:

1) smaller
2) the same
3) greater

Due to air friction, the ball is **continuously losing mechanical energy**. Therefore it has **less KE** (and consequently a **lower speed**) on the way down. **This means it will take more time on the way down** !!

Follow-up: How does the force of air resistance compare to gravity when the ball reaches terminal velocity?

Heat is K.E. and P.E. of molecules

- Mechanical energy lost to air resistance almost all goes to speed up the air molecules.
- Friction transfers energy mainly to microscopic vibrations of the surface: think of the atoms and molecules as balls held together with springs (the bonds), the balls will gain kinetic energy, the springs potential energy.
- These molecular energies are random and disorganized—not so easy to utilize as macroscopic energy.

Clicker Question

Just FYI – not for credit!

What is the approximate average speed of the oxygen molecules in your nose right now?

A. 5 cm/sec
B. 50 cm/sec
C. 5 m/sec
D. 50 m/sec
E. 500 m/sec

Other Kinds of Energy

- Electrical: electrostatic, magnetic, chemical (as in a charged battery). Unlike heat, energy properly stored electrically is almost fully recoverable.
- Electromagnetic radiation: light, heat, radio waves, etc., are all ways to transmit energy.
- Nuclear energy: energy stored in large nuclei during a star's explosion can be recovered.
- Bottom line: *total* energy is *always* conserved!

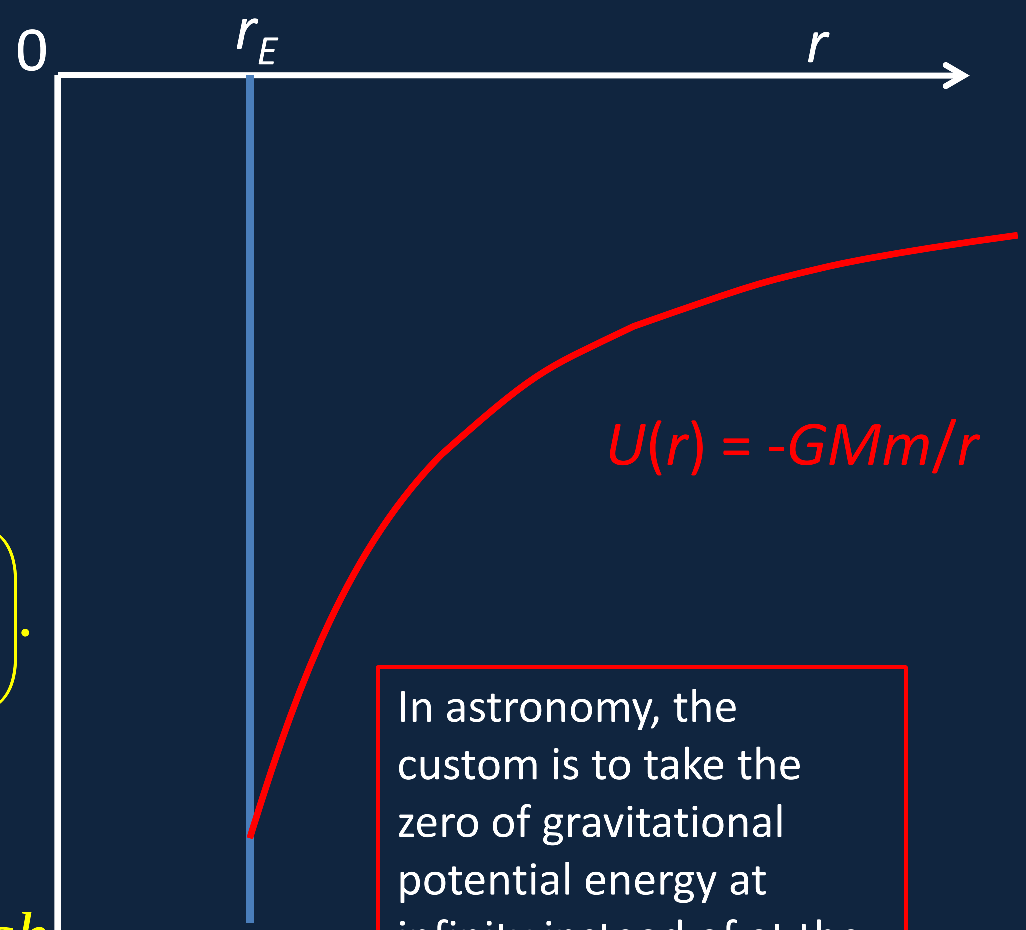
Gravitational Potential Energy…

- …*on a bigger scale*!
- For a mass *m* lifted to a point *r* from the Earth's center, far above the Earth's surface, the work done to lift it is

$$W = \int_{r_E}^{r} \frac{GMm}{r^2} dr = GMm\left(\frac{1}{r_E} - \frac{1}{r}\right).$$

- If $r = r_E + h$, with *h* small,

$$W = GMm\frac{r - r_E}{r r_E} \cong \frac{GMmh}{r_E^2} = mgh.$$



In astronomy, the custom is to take the zero of gravitational potential energy at infinity instead of at the Earth's surface.

Escape!

- We've figured out the work needed to get *m* from here to *r*,

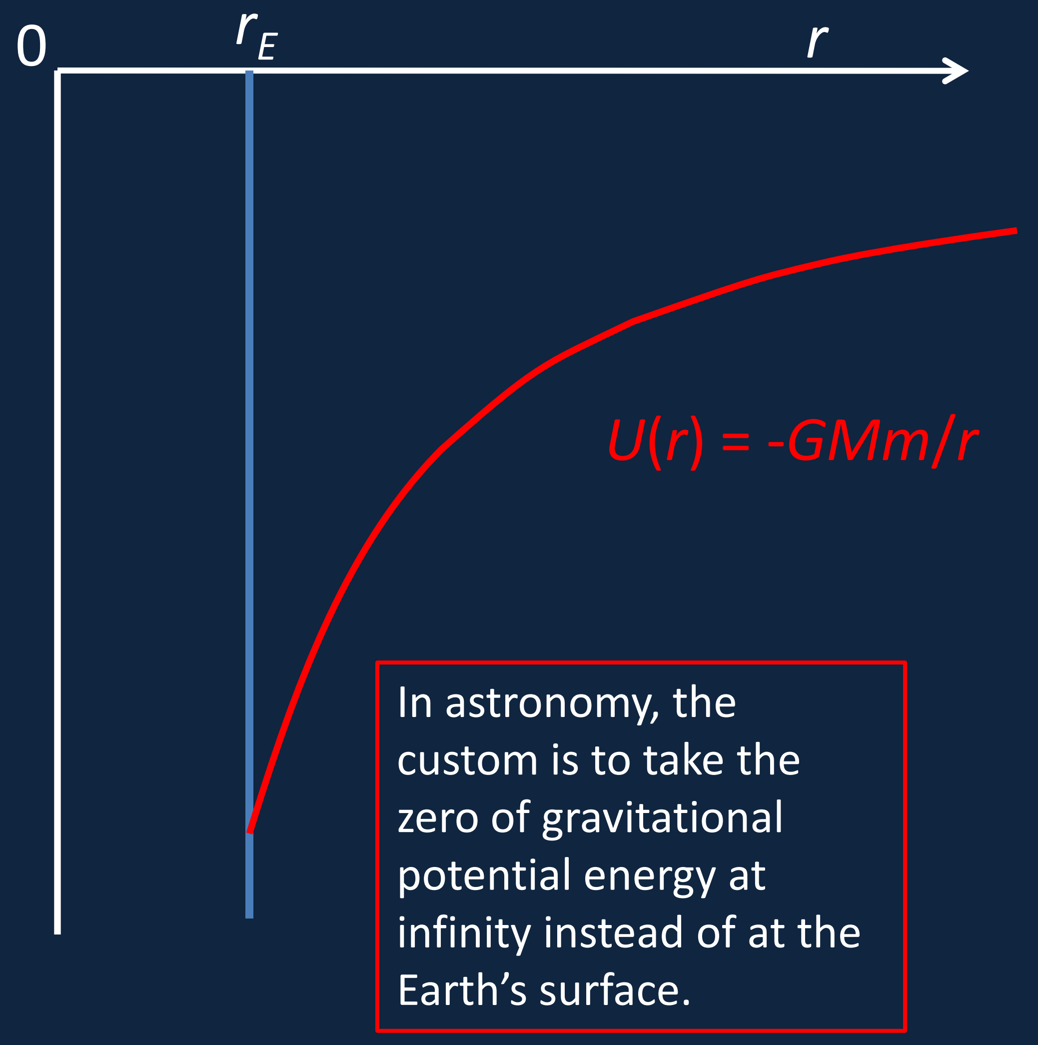
$$W = \int_{r_E}^{r} \frac{GMm}{r^2} dr = GMm\left(\frac{1}{r_E} - \frac{1}{r}\right).$$

and plotted the potential energy formula that comes from that:

$$U(r) = -GMm/r$$

- A mass leaving r_E at *v* will get all the way—escape—if:

$$\tfrac{1}{2}mv_{\text{esc}}^2 = GMm/r_E.$$



Escape Velocity and Orbital Velocity

- We've shown that escape velocity, starting at the Earth's surface, is given by

$$\tfrac{1}{2} m v_{\text{esc}}^2 = GMm / r_E.$$

- Recall that *orbital* velocity in a circular orbit just above the Earth's surface is given by

$$\frac{m v_{\text{orbit}}^2}{r_E} = \frac{GMm}{r_E^2}.$$

- It's easy to see that

$$\boxed{v_{\text{esc}}^2 = 2 v_{\text{orbital}}^2}$$

- Escaping takes twice the energy needed to get into low orbit!

Power

- In physics, power means *rate of working*.
- Work is measured in joules, so power is measured in joules per second.
- The unit of work is the watt:

1 watt = 1 joule per second

- Another unit of power is the horsepower:
- 1 horsepower (1 hp) = 746 watts.
- Note: electrical power (more next semester)
- 1 kW = 1,000 watts, 1 kWh = 3,600,000 joules.

Clicker Question

Ordinary steps have height about 17cm. Suppose you walk upstairs at 3 steps per second, and you weigh 70kg. What is your approximate rate of working?

A. 0.1 hp
B. 0.25 hp
C. 0.5 hp
D. 1 hp

Clicker Question

An automobile weighing 2,000 kg accelerates on a level road from rest to 30 m/sec in 9 secs. Ignoring friction, etc., what was its average power output during this period?

A. 50 hp
B. 130 hp
C. 180 hp
D. 250 hp