PHY131H1F - Class 22

Today we finish off Chapter 7:

7.8 Power

7.9 Gravitational Potential Energy in Space

1

Wake-up Poll Question!

A firecracker explodes in midair and suddenly breaks up into many fragments. Which of the following statements are true regarding conditions immediately before and immediately after the explosion:

I. The total momentum of the fragments is equal to the original momentum of the firecracker.

II. The total kinetic energy of the fragments is equal to the original kinetic energy of the firecracker.

A. Neither statement is true.

B. Statement I only

C. Statement II only

D. Both Statement I and Statement II

During a collision or explosion, the external impulse can be neglected.

Chemical Internal Energy is converted to kinetic energy.

2

A 0.50 kg basketball moving upward at 4.0 m/s strikes a 0.05 kg tennis ball, initially moving downward at 4.0 m/s. Their collision is perfectly elastic. What is the speed of the tennis ball immediately after the collision? 1 = basketball

$$v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_{1i} \qquad v_{2f} = \frac{2m_1}{m_1 + m_2} v_{1i}$$

(Elastic collision with ball 2 initially at rest.)

2 = tennis ball.

SKETCH & TRANSLATE.

Initial: Define +y

② $v_{2i} = -4$ m/s

① $v_{1i} = +4$ m/s

Final:

② $v_{2f} = ?$

① v_{1f} we don't care about.

SIMPLIFY & DIAGRAM

Let's switch to a reference frame where ball 2 = initially at rest. To do this, +4 m/s to all y-velocities. [Remember to −4 m/s at the end to get back to lab frame.

REPRESENT MATHEMATICALLY

Ball 2 initial rest frame: $v_{2i}' = 0$

$v_{1i}' = 4 + 4 = +8$ m/s

$$v_{2f}' = \frac{2m_1}{m_1 + m_2} v_{1i}' = \frac{2(0.5)}{0.5 + 0.05}(+8)$$

$v_{2f}' = +14.5$ m/s

SOLVE & EVALUATE

Convert back to lab frame:

$v_{2f} = (14.5 - 4)$ m/s

$v_{2f} = +10.5$ m/s ← fast.

3

Synchronous Midterm Assessment 4 Rubric

Tue, Nov. 17, 8:10-8:45pm Toronto Time

Done on Crowdmark: Two problems, you must write out the solutions

Based on Chs. 7, 8 and Practicals 3, 4a

SKETCH AND TRANSLATE (2 points)

- Ch. 7: Sketch the initial and final states of the process, Both: labeling the known and unknown information.
- Choose the system of interest.
- Include the object of reference and the coordinate system.
- For Ch.8 problems, include an axis of rotation.

4

Synchronous Midterm Assessment 4

SIMPLIFY AND DIAGRAM (2 points)

- State which simplifications can you make to the objects, interactions, and processes?
- Ch.7: State which energy types are changing.
- Ch.7: State whether or not external objects are doing work on your system.
- Ch.7: Use the initial and final sketches to help draw a work-energy bar chart.
- Ch.8: Draw a force diagram, showing the rotation axis and the places where the forces are applied

Synchronous Midterm Assessment 4

REPRESENT MATHEMATICALLY (2 points)

- Ch.7: Convert the bar chart into a mathematical description of the process.
- Ch.7: Each bar in the chart will appear as a single term in the equation.
- Ch.8: Use the force diagram to apply the conditions of equilibrium

SOLVE AND EVALUATE (2 points)

- Solve for the unknown and evaluate the result.
- Does it have the correct units? Is its magnitude reasonable? Do the limiting cases make sense?

Recap: Increase in the system's internal energy due to friction

Increase in the system's internal energy due to friction

$$\Delta U_{int} = +f_k d \quad (6.8)$$

where f_k is the magnitude of the average friction force exerted by the surface on the object moving relative to the surface and d is the distance that the object moves across that surface. The increase in internal energy is shared between the moving object and the surface.

$K_i + U_{gi} + W = K_f + U_{gf} + \Delta U_{int}$

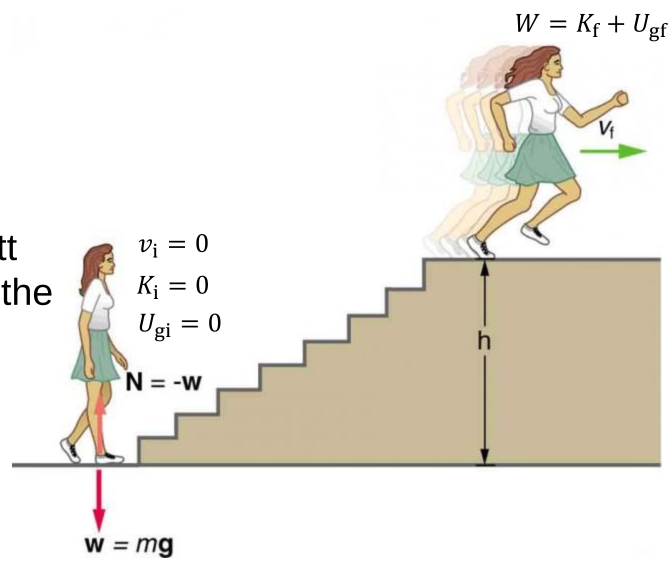
Including friction in the work-energy equation as an increase in the system's internal energy produces the **same result** as calculating the work done by the friction force.

7

7.8 Power

- Measure of *how fast* work is done
- In equation form:

$$Power = \frac{work\ done}{time\ interval}$$



Unit of power

- joule per second, called the watt after James Watt, developer of the steam engine
  - 1 joule/second = 1 watt
  - 1 kilowatt = 1000 watts

8

Poll Question

Rita raises a 10 kg package at constant speed to a height of 2.5 m in 2.0 s.

If she were to raise the same package to the same height in 1.0 s rather than 2.0 s, how would the work and power change?

A. the work and power would both stay the same
B. the work would stay the same, but the power would double
C. the work would double, but the power would stay the same
D. the work and power would both double

Poll Question

A sports car accelerates from zero to 30 mph in 1.5 s.
How long does it take for it to accelerate from zero to 60 mph, assuming the power of the engine to be independent of velocity and neglecting friction?

A. 2 s
B. 3 s
C. 4.5 s
D. 6 s
E. 9 s
F. 12 s

Electric Power

- The unit of power is the watt, which is defined as 1 watt = 1 W = 1 J/s
- Energy is measured by ~~Ontario~~ Hydro One (the company that sells electricity in this province) in kWh "kiloWatt hours".

- 1 kWh is the amount of energy used by a power of 1kW over 1 hour
- 1 kWh = 1000 J/s * 60 min/hour * 60 s/min
- 1 kWh = 3.6 million Joules

11

hydro one

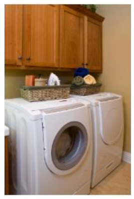
- Electricity in Ontario in 2019 came from Nuclear Power plants (58%), waterfalls and dams (24%), wind farms (8%), natural gas (6%), and solar/bioenergy (4%).
- The cost of electricity used to be adjusted depending on the time of day you were using it. It was more expensive to use electricity in your home during Mon-Fri 9-5 hours, and less expensive at night.
- Since COVID, the rates in Ontario have been fixed to one rate to accommodate people working from home.
- The COVID cost of electricity is $0.128/kWh for all hours of the day.

12

hydro one

- The COVID cost of electricity is $0.128/kWh for all hours of the day.

Your clothes dryer uses 5000 Watts and you need to run it for 1 hour to dry your clothes. How much does this cost?



$rate = 0.128 \frac{\$}{kWh}$

$cost = rate \cdot E = rate \cdot P \cdot \Delta t$

$P = \frac{E}{\Delta t}$

$E = P \Delta t$

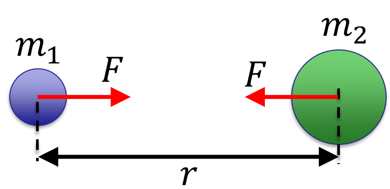
$cost = 0.128 \frac{\$}{kWh} \cdot 5\, kW \cdot 1\, hr$

$cost = 0.64\ \$$

13

Gravity Review

It was Newton who first recognized that **gravity is an attractive, long-range force between *any* two objects.**



When two objects have masses m_1 and m_2 and centers are separated by distance r, each object attracts the other with a force given by Newton's law of gravity, as follows:

$$F = \frac{G m_1 m_2}{r^2}$$

where $G = 6.67 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}$ is the Gravitational constant (the same everywhere in the universe).

14

Gravitational Potential Energy

When two isolated masses m_1 and m_2 interact over large distances, they have a gravitational potential energy of

$$U_g = -\frac{Gm_1m_2}{r}$$

always negative.

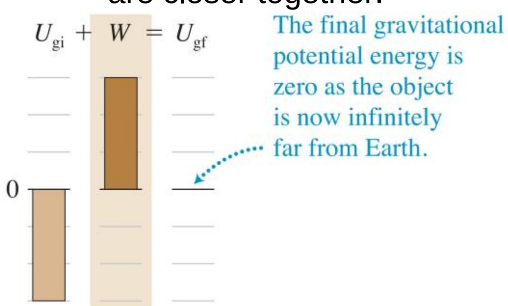
where we have chosen the zero point of potential energy at $r = \infty$, where the masses will have no tendency, or potential, to move together.

Note that this equation gives the potential energy of masses m_1 and m_2 when their *centers* are separated by a distance r.

15

Gravitational potential energy and negative energy

- The gravitational potential energy is zero when the objects are an infinite distance apart.
  - The only way to add positive energy to a system and have it become zero is if it starts with negative energy.
  - The gravitational potential energy is therefore negative when the objects are closer together.



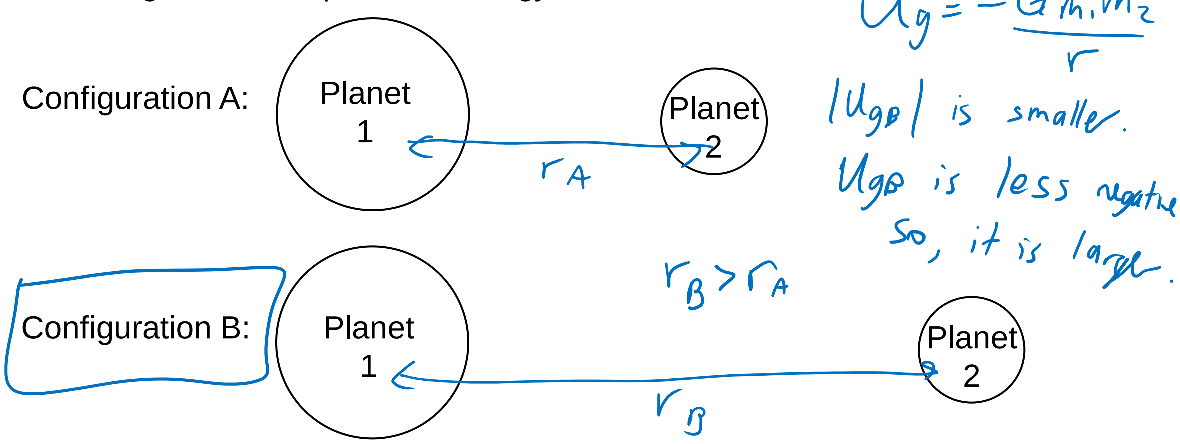
Note: for an object on earth, we can set $m_2 = m$, the mass of the object, $m_1 = m_E$, the mass of the Earth, and $r = r_E$, the radius of the Earth.

$$U_g = -\frac{Gm_Em}{r_E}$$

16

Poll Question

- In the diagram below, two different configurations of planets 1 and 2 are shown.
- In configuration B, the two planets are further apart than in configuration A.
- If we consider planets 1 and 2 as a system together, which configuration (A or B) has more gravitational potential energy?



17

How can two equations that look so different be about the same thing?

$$U_g = mgy \qquad\qquad U_g = -\frac{Gm_E m}{r_E}$$

- **Let's do an Example:** A 5 kg cat starts at ground level, and then goes up to the restaurant of the CN Tower, 350 m up.
- Using the good-old approximate equation, $U_g = mgy$, calculate the change in gravitational potential energy of the cat.
- $\Delta U_g = mgy_2 - mgy_1$ = (5 kg) (9.8 m/s^2) (350) – 0 = 17,000 Joules
- Next, let's try the correct equation, $U_g = -\frac{Gm_E m}{r}$, and re-calculate the change in gravitational potential energy of this cat.

18

How can two equations that look so different be about the same thing?

~~$\frac{1}{\infty} = 0$~~

$\lim_{r \to \infty} \left(\frac{1}{r} \right) = 0$

$$U_g = mgy \qquad\qquad U_g = -\frac{G m_E m}{r_E}$$

- Using the correct equation, $U_g = -\frac{G m_E m}{r}$, calculate the change in gravitational potential energy of the cat.
- Note that the base of the CN tower is at a distance of about $r_1 = 6{,}371{,}000$ m from the centre of the Earth. If that's exactly true, then the restaurant is $r_2 = 6{,}371{,}350$ m from the centre of the earth.
- $\Delta U_g = -\frac{G m_E m}{r_2} - \left(-\frac{G m_E m}{r_1}\right) = G m_E m \left(\frac{1}{r_1} - \frac{1}{r_2}\right)$
- $\Delta U_g = (6.7 \times 10^{-11})(6.0 \times 10^{24})(5)\left(\frac{1}{6{,}371{,}000} - \frac{1}{6{,}371{,}350}\right) = 17{,}000$ Joules!

19

How can two equations that look so different be about the same thing?

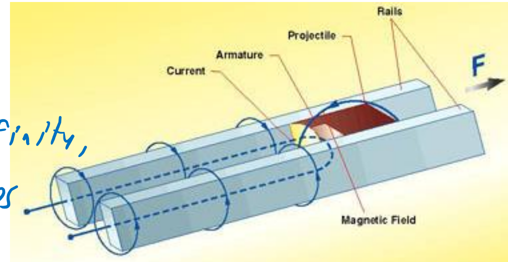
$$U_g = mgy \qquad\qquad U_g = -\frac{G m_E m}{r_E}$$

approximate — exact.

- Actually, the zero-points of these two equations are quite different.
- $U_g = mgy$ is zero at the Earth's surface, while $U_g = -\frac{G m_E m}{r_E}$ is zero at infinity.
- But, since the zero-point is arbitrary, these two equations are physically the same, as long as you are not too far from the Earth's surface!

20

Launching a spacecraft



$K_i + U_{gi} = K_f + U_{gf}$ ($K_f \geq 0$, $U_{gf} = 0$) at infinity, it stops

$U_{gi} = -\frac{G m m_E}{r_E}$

- People have considered making a spacecraft launch system using a rail gun
- (Don’t worry about the technical details of this: basically imagine a big gun on Earth’s surface shooting the spacecraft into space.)
- What is the minimum speed the spacecraft must be launched at from Earth’s surface in order to completely escape Earth’s gravity?
- Note: In order to get to $r \rightarrow \infty$ and stop, the final energy must equal zero. So the initial energy must be at least zero.

21

Before Class 23 on Wednesday

- Please start reading Chapter 8:
- 8.1 Extended Objects
- 8.2 Torque

- Remember on tomorrow by 8:45pm you have to upload your Ch.8 Prequiz onto the Crowdmark site. It’s worth 16 homework credits for good-faith participation by the deadline (this one won’t be carefully marked).

22