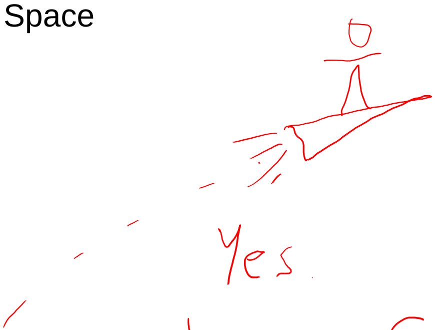
PHY131H1F - Hour 22

Today we finish off Chapter 7:

7.8 Power

7.9 Gravitational Potential Energy in Space



Yes

I am Spock

Wake-up LC 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

Chemical energy tranformed into Kinetic energy

PHY131H1F - Hour 22

- Today will take us to the end of the testable material for the second midterm, which will cover chapters 5, 6 and 7.
- Recall, the second midterm is on Tuesday Nov. 13th, from 6:10pm - 7:30pm.
- If you have a course conflict you will be permitted to register to write at the alternative sitting on Tuesday Nov. 13th, from 4:40pm - 6:00pm.
- If you already registered for the first midterm for the alternate sitting, you do not need to re-register for the second midterm; you are automatically in the alternative sitting for the second midterm.

Thoughts from students…

- *"The fact that pages in the textbook are not physically connected and the textbook falls apart."*
- **Harlow answer:** Hmm. You must get organized. On staples.ca search up "binders" or "duotangs".
- *"In the grades section on Quercus for this course, I have grades listed under LC hour 19, 20, and 21. Is this the lecture participation grade since the new professor started?"*
- **Harlow answer:** Yes it's the Learning Catalytics in-class mark from when I took over. I dislike how, in the MasteringPhysics gradebook, half of the Learning Catalytics marks are always zeros. So, when I transferred the Learning Catalytics marks from MasteringPhysics to Quercus using Excel, I was able to eliminate the zeros.

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.

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.

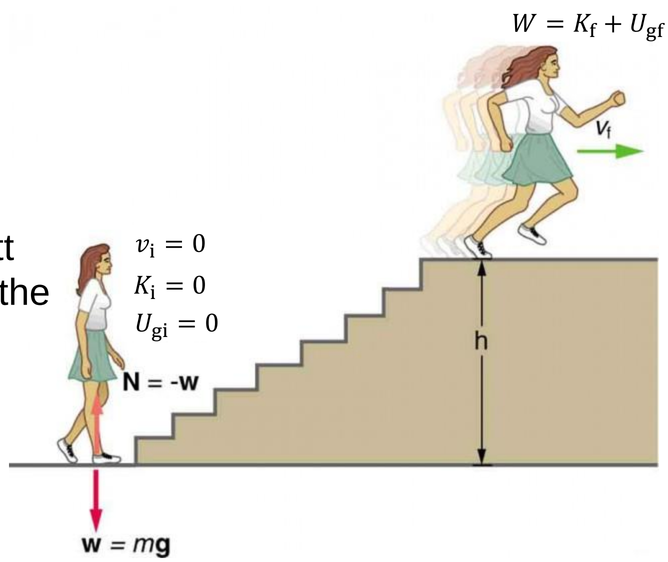
7.8 Power

- 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



Learning Catalytics 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

Learning Catalytics 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

Power = constant = $\frac{\Delta E}{\Delta t}$ $\quad P = \frac{\Delta E}{\Delta t} \Rightarrow \Delta t = \frac{\Delta E}{P}$

$\Delta E = K_f - K_i^{\,\nearrow 0}$

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

$\Delta t = \frac{\frac{1}{2} m v_f^2}{P}$

$\Delta t_1 = 1.5\,s$. Δt_2 has v_f doubled.

$\Delta t_2 = 2^2 \Delta t_1 = 4(1.5)$

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 (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

http://www.ontario-hydro.com/current-rates

Ontario Hydro

- **Time-of-Use Pricing (TOU)**
- Electricity in Ontario comes from Nuclear Power plants (63%), waterfalls and dams (26%), wind farms (6%), and gas/oil (4%).
- These sources provide power 24 hours per day, 7 days per week, but humans demand energy on a schedule, which means some energy must be **stored**, which is expensive, and leads to inefficiencies.
- "By adjusting your usage habits, TOU pricing enables you to save money during hours when electricity is more expensive, and it helps Ontario Hydro with storage issues."

[go to Doc Cam Example]

<table>
<tr><th>From</th><th>To</th><th>Summer Rate (May - Oct)</th><th>Winter Rate (Nov - Apr)</th></tr>
<tr><td>7:00 AM</td><td>8:00 AM</td><td rowspan="4">mid-peak rate
9.4 cents/kWh</td><td rowspan="4">on-peak rate
13.2 cents/kWh</td></tr>
<tr><td>8:00 AM</td><td>9:00 AM</td></tr>
<tr><td>9:00 AM</td><td>10:00 AM</td></tr>
<tr><td>10:00 AM</td><td>11:00 AM</td></tr>
<tr><td>11:00 AM</td><td>12:00 PM</td><td rowspan="6">on-peak rate
13.2 cents/kWh</td><td rowspan="6">mid-peak rate
9.4 cents/kWh</td></tr>
<tr><td>12:00 PM</td><td>1:00 PM</td></tr>
<tr><td>1:00 PM</td><td>2:00 PM</td></tr>
<tr><td>2:00 PM</td><td>3:00 PM</td></tr>
<tr><td>3:00 PM</td><td>4:00 PM</td></tr>
<tr><td>4:00 PM</td><td>5:00 PM</td></tr>
<tr><td>5:00 PM</td><td>6:00 PM</td><td rowspan="2">mid-peak rate
9.4 cents/kWh</td><td rowspan="2">on-peak rate
13.2 cents/kWh</td></tr>
<tr><td>6:00 PM</td><td>7:00 PM</td></tr>
<tr><td>7:00 PM</td><td>8:00 PM</td><td rowspan="12">off-peak rate
6.5 cents/kWh</td><td rowspan="12">off-peak rate
6.5 cents/kWh</td></tr>
<tr><td>8:00 PM</td><td>9:00 PM</td></tr>
<tr><td>9:00 PM</td><td>10:00 PM</td></tr>
<tr><td>10:00 PM</td><td>11:00 PM</td></tr>
<tr><td>11:00 PM</td><td>Midnight</td></tr>
<tr><td>Midnight</td><td>1:00 AM</td></tr>
<tr><td>1:00 AM</td><td>2:00 AM</td></tr>
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<tr><td>5:00 AM</td><td>6:00 AM</td></tr>
<tr><td>6:00 AM</td><td>7:00 AM</td></tr>
</table>

Note
Off peak rates are charged on weekends and holidays. The rates shown to the left apply Monday to Friday.

Your clothes dryer uses 5000 Watts and you need to run it for 1 hour to dry your clothes.

If you run it during "on-peak" time, such as between 7 and 11am on a weekday, the cost is 13.2 cents/kWh.

If you run it during "off-peak" on the weekend, the price for Ontario Hydro electricity is 6.5 cents/kWh.

How much money do you save **per load** by doing your laundry on the weekend? If you do 50 loads in a semester, how do you save?

Represent mathematically

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

P = 5000 Watts

1 load = 1 hour = Δt

$\Delta E = P \Delta t$

$= (5 \text{ kW}) 1 \text{ hr}$

$\Delta E = 5 \text{ kWh}$

Rate "on peak" = 13.2 $\frac{\text{cents}}{\text{kWh}}$

"off peak" = 6.5 $\frac{\text{cents}}{\text{kWh}}$

Solve and Evaluate

Cost = Rate × ΔE

$\text{cost}_{on} = 13.2 \cdot 5 = 66$ cents

$\text{Cost}_{off} = 6.5\,(5) = 32.5$ cents

Savings = $\text{Cost}_{on} - \text{cost}_{off}$

= 66 - 32

Savings = 33.5 cents

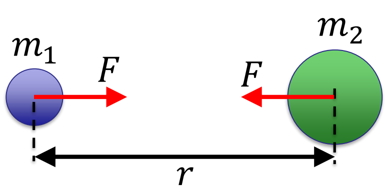
50 loads

Saving 50(33.5) = 1675c

= $16.75

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

Gravitational Potential Energy

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

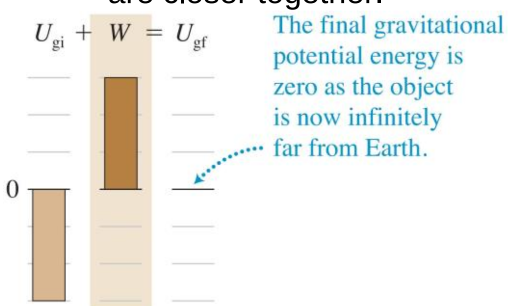
$$U_g = -\frac{Gm_1m_2}{r}$$

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.

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.

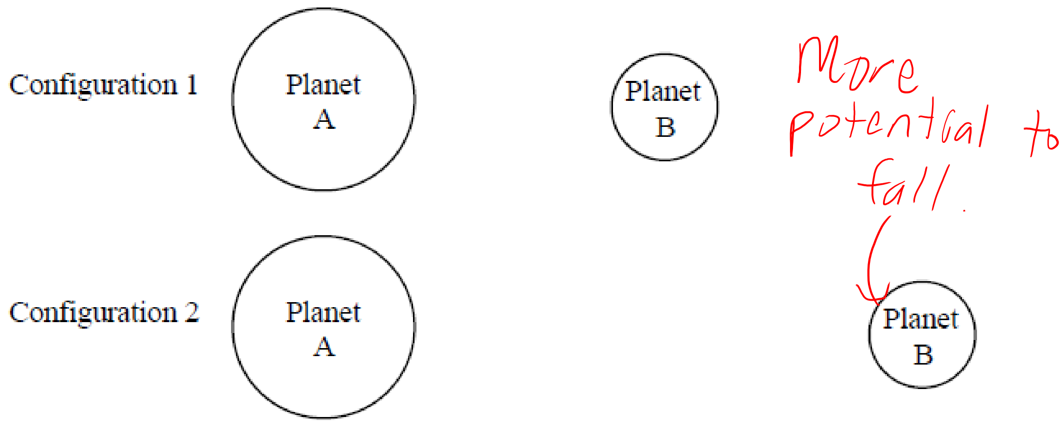


Note: for an object on earth, we can set $m_2 = m$, the mass of the object, $m_1 = m_E$, the mass of the Earth, and $r = r_E$, the radius of the Earth.

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

Learning Catalytics Question

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



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

$$U_g = mgy$$

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

- **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.

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

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

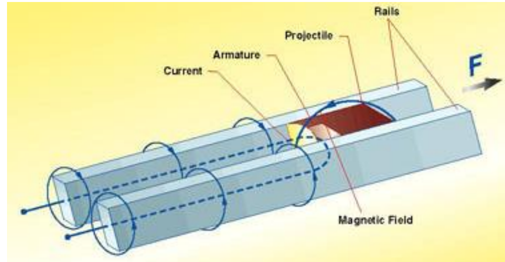
- Using the correct equation, $U_g = -\frac{Gm_E m}{r}$, calculate the change in gravitational potential energy of the cat.
- Note that the base of the CN tower is at a distance of about $r_1 = 6{,}371{,}000$ m from the centre of the Earth. If that's exactly true, then the restaurant is $r_2 = 6{,}371{,}350$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

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

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

- Actually, the zero-points of these two equations are quite different.
- $U_g = mgy$ is zero at the Earth's surface, while $U_g = -\frac{Gm_E m}{r_E}$ 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!

Launching a spacecraft

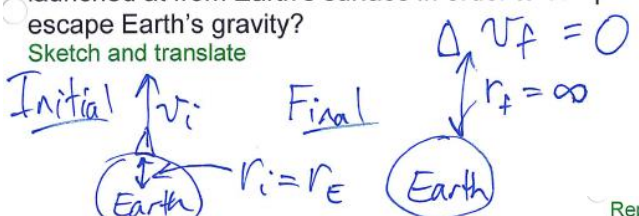


- People have considered making a spacecraft launch system using a rail gun
- (Don't worry about the technical details of this: basically imagine a big gun on Earth's surface shooting the spacecraft into space.)
- What is the minimum speed the spacecraft must be launched at from Earth's surface in order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

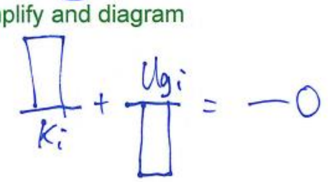
[go to Doc Cam Example]

What is the minimum speed the spacecraft must be launched at from Earth's surface in order to completely escape Earth's gravity?

Sketch and translate



Simplify and diagram



Represent mathematically

$$\frac{1}{2} m v_i^2 + \left(-\frac{G m_E m}{r_i} \right) = 0$$

Solve and Evaluate

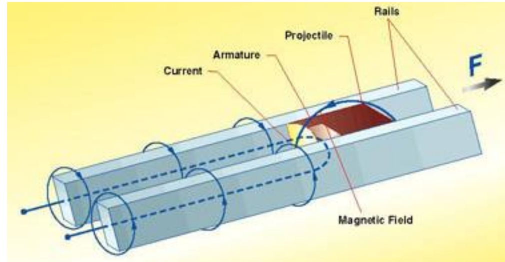
$$v_i^2 = \frac{2 G m_E}{r_E}$$

$$v_i = \sqrt{\frac{2 G m_E}{r_E}} = \sqrt{\frac{2(6.67\times10^{-11})(5.97\times10^{24})}{6.38\times10^{6}}}$$

$$v_i = 11{,}000 \text{ m/s} = 11 \text{ km/s}$$

VERY FAST

Launching a spacecraft



- Answer:

$$v_{\mathrm{escape}} = \sqrt{\frac{2Gm_{\mathrm{E}}}{r_{\mathrm{E}}}}$$

- For Earth, this is about 11 km/s.
- Anything going this fast through the air would be instantly vapourized and explode, due to air friction.
- Notice: The escape speed does **not depend** on the mass of the escaping object: a tiny speck of dust and a huge boulder would need the same initial speed to leave Earth.

Learning Catalytics Question

- Planet A has twice the mass of Planet B. From this information, what can we conclude about the escape speed for Planet A compared to that of Planet B?
  - A. The escape speed for Planet A must be twice as great as the escape speed from Planet B.
  - B. The escape speed for Planet A must be four times as great as the escape speed from Planet B.
  - C. The escape speed for Planet A is the same as the escape speed from Planet B.
  - D. The escape speed for Planet A is greater than the escape speed from Planet B, but we cannot say how much greater.
  - E. We cannot conclude anything about the escape speed for Planet A without knowing the radii of the two planets.

Black holes

$$v_{\text{escape}} = \sqrt{\frac{2Gm_E}{r_E}}$$

- The equation for escape speed suggests something amazing:
  - If the mass of the Earth were large enough or its radius small enough, the escape speed could be very large.
  - If any object’s escape speed were faster than the speed of light, light leaving the star's surface would not be moving fast enough to escape; the star would be completely dark!

There is a supermassive black hole at the centre of our galaxy!

- https://www.nytimes.com/2018/10/30/science/black-hole-milky-way.html

By Dennis Overbye

Oct. 30, 2018 59

In a dark, dusty patch of sky in the constellation Sagittarius, a small star, known as S2 or, sometimes, S0-2, cruises on the edge of eternity. Every 16 years, it passes within a cosmic whisker of a mysterious dark object that weighs some 4 million suns, and that occupies the exact center of the Milky Way galaxy.