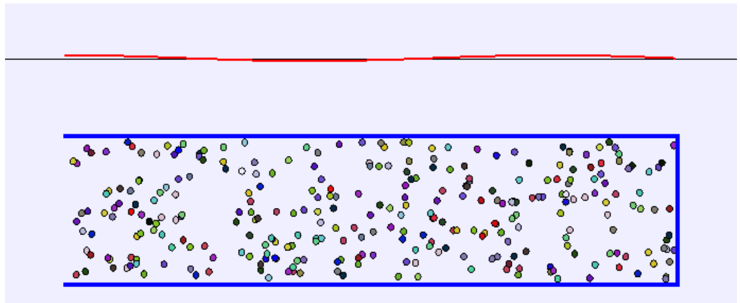
PHY131H1F - Hour 34 – Where did the semester go?



This is a standing wave of sound in an open-closed tube.

Today:

11.7 Sound Waves, Beats

11.8 Standing Waves on Strings

11.9 Standing Waves in Air Columns

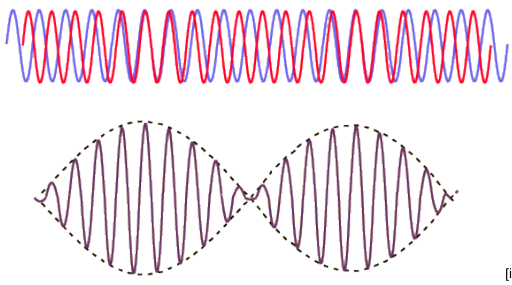
Latest Comments from Learning Catalytics: "Please enter at least one specific question or concern you would like me to address in class."

- *"How does the small angle approximation work?"*
- **Harlow answer:** when θ is measured in radians, then:
- $\sin\theta \approx \theta$
- This helps in many cases, for example whenever you have a tall skinny isosceles triangle.

Angle [deg]	Angle [rad]	sine	% error	sig figs
0.1	0.00174533	0.00174533	0.0001%	6
1	0.01745	0.01745	0.01%	4
3	0.05236	0.05234	0.05%	3
5	0.08727	0.08716	0.13%	2
10	0.17453	0.17365	0.51%	2
15	0.26180	0.25882	1.15%	2
20	0.34907	0.34202	2.06%	1
25	0.43633	0.42262	3.25%	1

Beats

- Periodic variations in the loudness of sound due to interference
- Occur when two waves of similar, but not equal frequencies are superposed.
- Provide a comparison of frequencies
- Frequency of beats is equal to the **difference** between the frequencies of the two waves.



[image from http://hyperphysics.phy-astr.gsu.edu/hbase/sound/beat.html]

Beats

- Applications
  - Piano tuning by listening to the disappearance of beats from a known frequency and a piano key
  - Tuning instruments in an orchestra by listening for beats between instruments and piano tone

Beat and beat frequencies

A **beat** is a wave that results from the superposition of two waves of about the same frequency. The beat (the net wave) has a frequency equal to the average of the two frequencies and has variable amplitude. The frequency with which the amplitude of the net wave changes is called the **beat frequency** f_{beat}; it equals the difference in the frequencies of the two waves:

$$f_{beat} = |f_1 - f_2| \tag{20.10}$$

Learning Catalytics Question

- If you combine the sounds of two pure tones, one with a frequency of 440 Hertz, and the other with a frequency of 220 Hertz, what do you get?

A. Beats with a frequency of 2 Hertz
B. Beats with a frequency of 220 Hertz
C. Beats with a frequency of 440 Hertz
D. A continuous sound which humans perceive to be two tones played at once

Learning Catalytics Question

- You are tuning a piano and you want to make the frequency of an A key to be 440 Hertz, but you suspect it is out of tune.
- You have a reference sound source that you know for sure makes a pure tone of 440 Hertz.
- When you sound the reference at the same time as the piano A key, you hear 3 beats per second.
- What is the frequency of your out-of-tune piano A key?

A. 440 Hz

B. 443 Hz

C. 437 Hz

D. It's impossible to know with the information given

Learning Catalytics Question

- You are tuning a piano and you want to make the frequency of the A key to be 440 Hertz, but you suspect it is out of tune. You have a reference sound source that you know for sure makes a pure tone of 440 Hertz. When you sound the reference at the same time as your out-of-tune piano A key, you hear 3 beats per second.
- You then tighten the string on the piano, which you know raises the frequency of the A key a bit. When you sound the reference at the same time now, you hear 7 beats per second! What is the new frequency of the out-of-tune piano A key?

A. 440 Hz

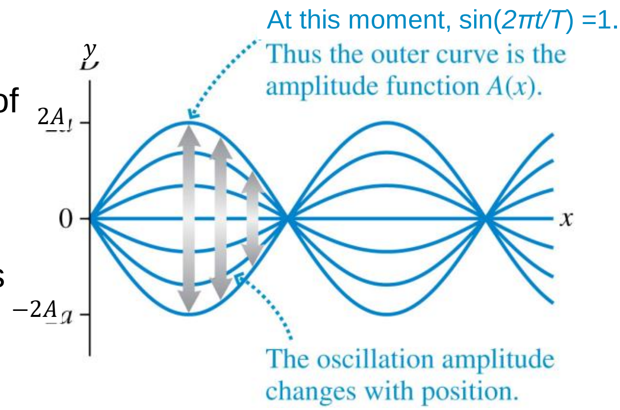
B. 447 Hz

C. 433 Hz

D. It's impossible to know with the information given

The Mathematics of Standing Waves

- Shown is the graph of $y(x,t)$ at several instants of time.
- The nodes occur at $x_m = m\lambda/2$, where m is an integer.



$$y(x,t) = A(x)\sin\left(\frac{2\pi}{T}t\right) \qquad A(x) = 2A\sin\left(\frac{2\pi}{\lambda}x\right)$$

Standing Waves on a String

For a string of fixed length L, the boundary conditions can be satisfied only if the wavelength has one of the values:

$$\lambda_m = \frac{2L}{m} \qquad m = 1, 2, 3, 4, \ldots$$

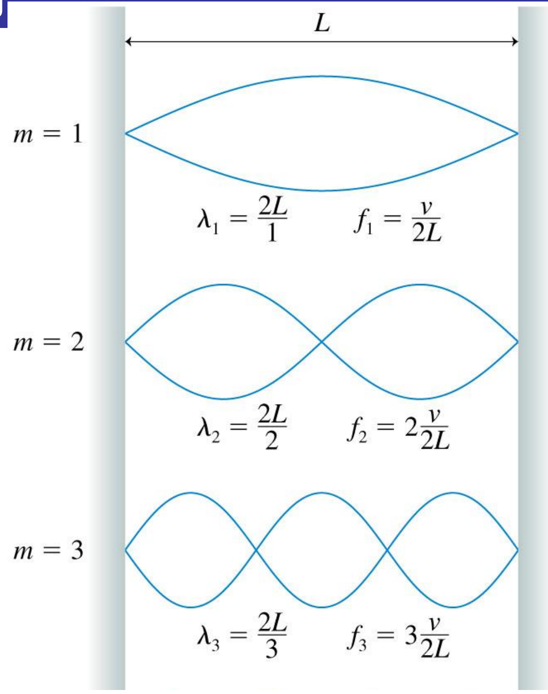
Because $\lambda f = v$ for a sinusoidal wave, the oscillation frequency corresponding to wavelength λ_m is:

$$f_m = \frac{v}{\lambda_m} = \frac{v}{2L/m} = m\frac{v}{2L} \qquad m = 1, 2, 3, 4, \ldots$$

The lowest allowed frequency is called the **fundamental frequency**: $f_1 = v/2L$.

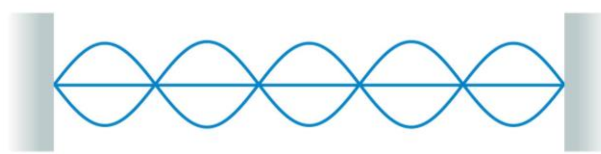
Standing Waves on a String

- Shown are various standing waves on a string of fixed length L.
- These possible standing waves are called the **modes** of the string, or sometimes the *normal modes.*
- Each mode, numbered by the integer m, has a unique wavelength and frequency.



Learning Catalytics Question

What is the mode number of this standing wave?



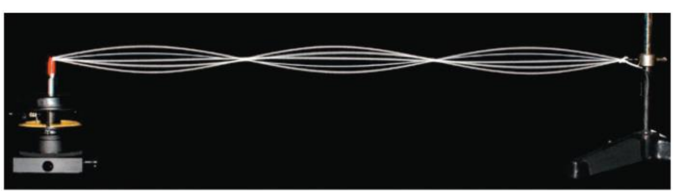
Standing Waves on a String

There are three things to note about the normal modes of a string:

1. *m* is the number of *antinodes* on the standing wave.
2. The *fundamental mode*, with $m = 1$, has $\lambda_1 = 2L$.
3. The frequencies of the normal modes form a series: f_1, $2f_1$, $3f_1$, …These are also called **harmonics**. $2f_1$ is the “second harmonic”, $3f_1$ is the “third harmonic”, etc.

Standing Waves on a String

- *m* is the number of *antinodes* on the standing wave.
- The *fundamental mode*, with $m = 1$, has $\lambda_1 = 2L$.
- The frequencies of the normal modes form a series: f_1, $2f_1$, $3f_1$, …
- The fundamental frequency f_1 can be found as the *difference* between the frequencies of any two adjacent modes: $f_1 = \Delta f = f_{m+1} - f_m$.
- Below is a time-exposure photograph of the $m = 3$ standing wave on a string.



Learning Catalytics Discussion Question

The frequency of the third harmonic of a string is

A. One-third the frequency of the fundamental.
B. Equal to the frequency of the fundamental.
C. Three times the frequency of the fundamental.
D. Nine times the frequency of the fundamental.

Sound Waves

- Your ears are able to detect sinusoidal sound waves with frequencies between about $20\ \mathrm{Hz}$ and $20\ \mathrm{kHz}$.

- Low frequencies are perceived as “low pitch” bass notes, while high frequencies are heard as “high pitch” treble notes.
- Sound waves with frequencies above $20\ \mathrm{kHz}$ are called *ultrasonic* frequencies.
- Oscillators vibrating at frequencies of many MHz generate the ultrasonic waves used in ultrasound medical imaging.

Image from http://www.weblocal.ca/uc-baby-3d-ultrasound-brampton-on.html

Standing Sound Waves

- A long, narrow column of air, such as the air in a tube or pipe, can support a longitudinal standing sound wave.
- An open end of a column of air must be a pressure node (always at ambient pressure), thus the boundary conditions—nodes at the ends—are the same as for a standing wave on a string.
- A closed end forces a pressure antinode.

Musical Instruments

- With a wind instrument, blowing into the mouthpiece creates a standing sound wave inside a tube of air.
- The player changes the notes by using her fingers to cover holes or open valves, changing the length of the tube and thus its fundamental frequency:

$$f_1 = \frac{v}{2L}$$ for an open-open tube instrument, such as a flute

$$f_1 = \frac{v}{4L}$$ for an open-closed tube instrument, such as a clarinet

- In both of these equations, v is the speed of sound in the air *inside* the tube.
- Overblowing wind instruments can sometimes produce higher harmonics such as $f_2 = 2f_1$ and $f_3 = 3f_1$.

$$\begin{cases} \lambda_m = \dfrac{2L}{m} \\ f_m = m\dfrac{v}{2L} = mf_1 \end{cases} \qquad m = 1, 2, 3, 4, \ldots \quad \text{(open-open or closed-closed tube)}$$

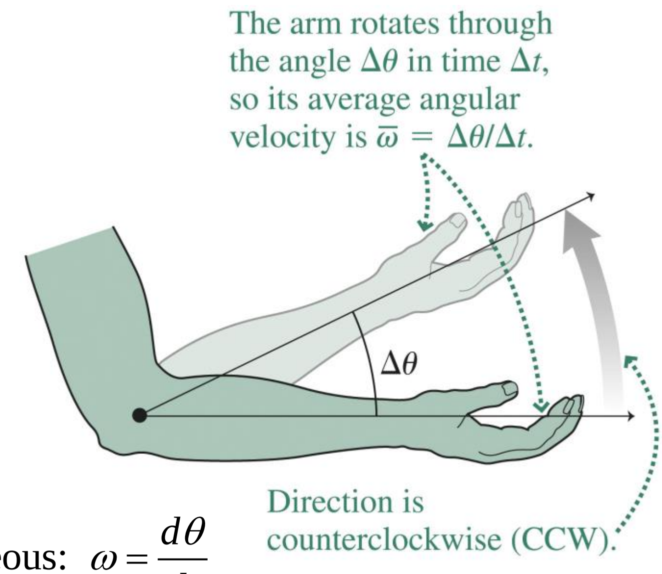
$$\begin{cases} \lambda_m = \dfrac{4L}{m} \\ f_m = m\dfrac{v}{4L} = mf_1 \end{cases} \qquad m = 1, 3, 5, 7, \ldots \quad \text{(open-closed tube)}$$

Review: Instantaneous Velocity

- The instantaneous velocity at time t is the average velocity during a time interval Δt centered on t, as Δt approaches zero
- In calculus, this is called *the derivative of x with respect to t*
- Graphically, $\Delta x/\Delta t$ is the slope of a straight line
- In the limit $\Delta t \rightarrow 0$, the straight line is **tangent** to the curve
- The instantaneous velocity at time t is the slope of the line that is tangent to the position-versus-time graph at time t

v = the slope of the position-versus-time graph at t

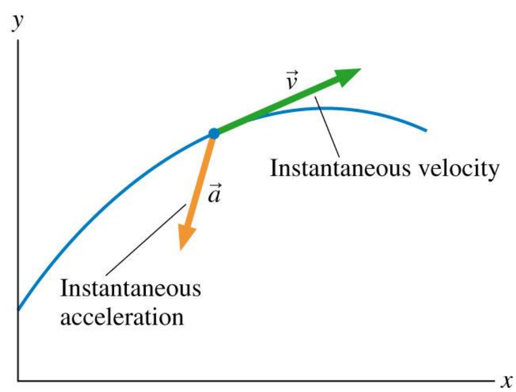
Review: Angular Velocity



Instantaneous: $\omega = \frac{d\theta}{dt}$

Review: Acceleration

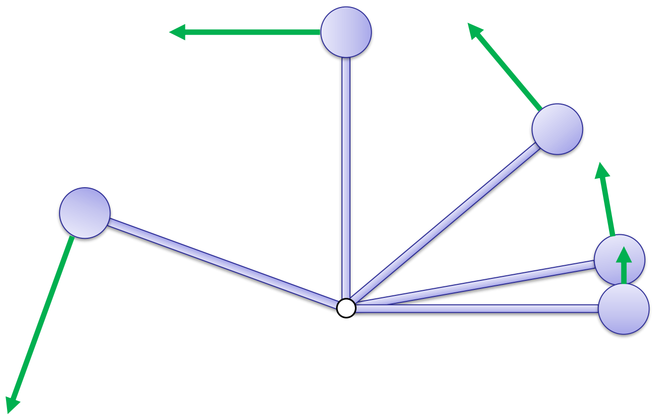
- By definition, $\vec{a}$ is the rate at which $\vec{v}$ is changing at that instant.



Review: Angular Acceleration

- Angular acceleration α is the rate of change of angular velocity.

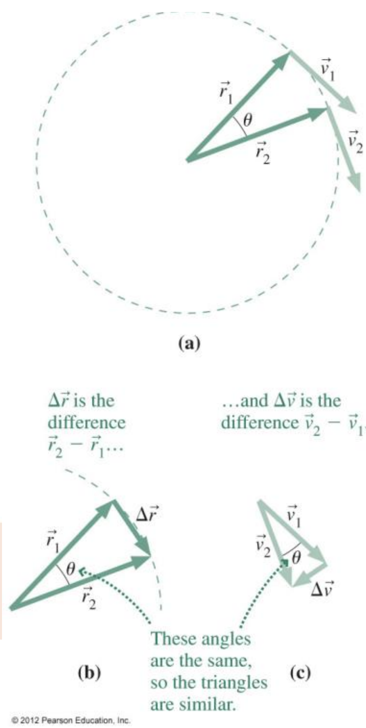
$$\text{Average: } \bar{\alpha} = \frac{\Delta\omega}{\Delta t} \qquad \text{Instantaneous: } \alpha = \frac{d\omega}{dt}$$



Review: Centripetal Acceleration

- The figure shows the velocity $\vec{v}_1$ at one instant and the velocity $\vec{v}_2$ an infinitesimal amount of time dt later
- By definition, $\vec{a} = d\vec{v}/dt$
- By analyzing the isosceles triangle of velocity vectors, we can show that:

$$\vec{a} = \left(\frac{v^2}{r}, \text{ toward center of circle}\right)$$



Review: Static Friction

- A shoe pushes on a wooden floor but does not slip.
- On a microscopic scale, both surfaces are “rough” and high features on the two surfaces touch and adhere.
- This produces force *parallel* to the surface, called the **static friction** force.
- With increased normal force, the shapes ‘lock-together’ better, there’s more contact area, hence the maximum friction force increases.

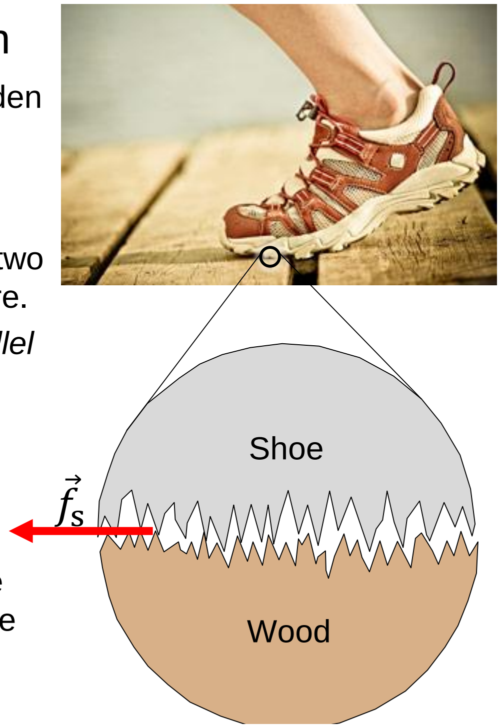


Image from http://www.which.co.uk/home-and-garden/leisure/reviews/walking-shoes/best-buy/about/

Gravitational Potential Energy

- It’s convenient to take the zero of gravitational potential energy at infinity. Then the gravitational potential energy becomes

$$U(r) = -\frac{GMm}{r}$$

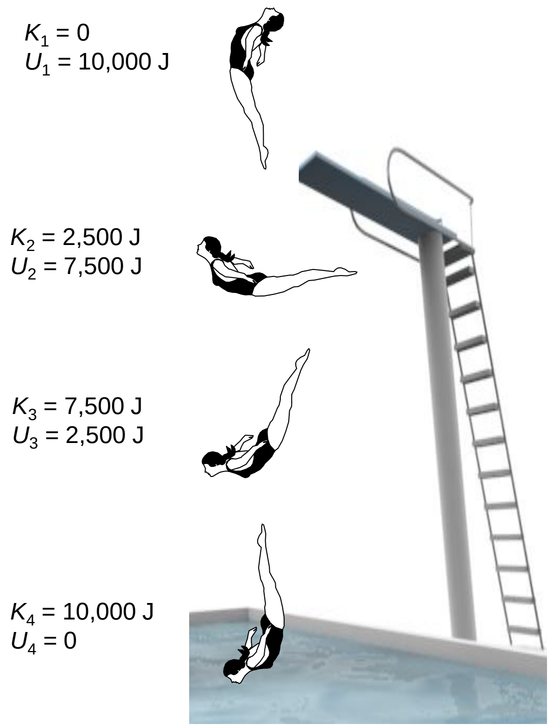
- When $r = R + y$, with $y << R$, we can redefine the zero-point of gravitational potential energy to be at $r = R$.
- Then we have an approximate equation:

$$U \approx \frac{GMm}{R^2} y = mgy$$

- Where $g = GM/R^2$ is the acceleration due to gravity at $r = R$.

Review: Conservation of Mechanical Energy

$$K_1 + U_1 = K_2 + U_2$$



Law of conservation of momentum:

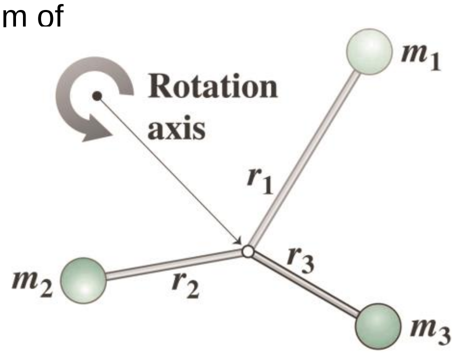
In the absence of an external force, the momentum of a system remains unchanged.

This is usually applied during brief collisions or explosions, in which internal forces are much much greater than any external forces for a short time.

Review: Rotational Inertia

- For a system of discrete masses, the rotational inertia is the sum of the rotational inertias of the individual masses:

$$I = \sum m_i r_i^2$$



The Final Exam!

PHY131H1F	A - LEE	TUE 11 DEC	EV 7:00 - 10:00	EX 100
PHY131H1F	LEN - YO	TUE 11 DEC	EV 7:00 - 10:00	EX 200
PHY131H1F	YU - Z	TUE 11 DEC	EV 7:00 - 10:00	EX 300

- EX is Central Exams Facility, 255 McCaul St. (just south of College St.)

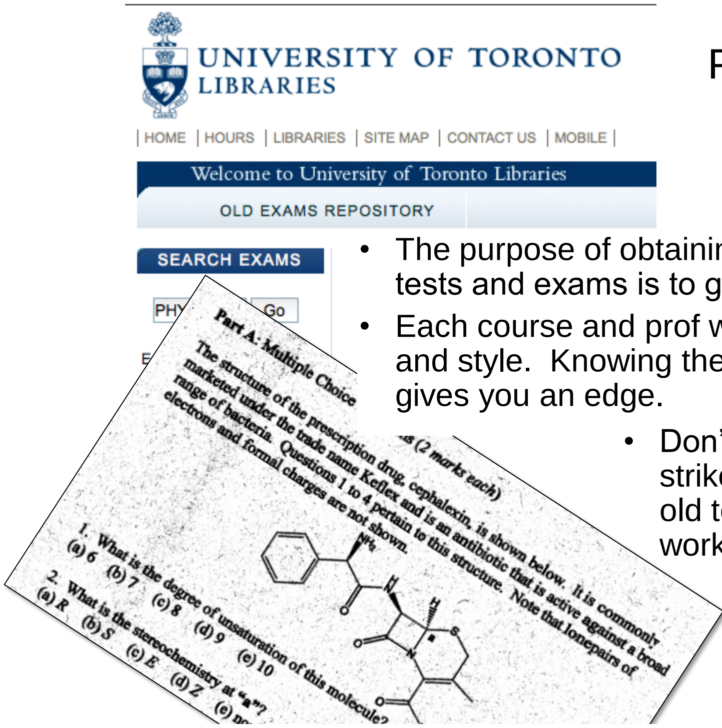
What to expect

- 3 hours.
- 24 multiple choice questions worth 2 points each, which you do by scratching one of those cards very carefully (48 points total)
- 2 long-answer problems worth 8 points each for which you must show your work using the four-step method from the textbook (16 points total).
- Final exam is out of 64 points.

Study Groups – working with Peers

- Find student (students) in class that you work well with on MasteringPhysics, end-of-chapter suggested problems, and past tests.

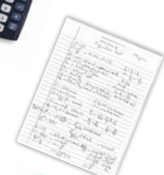
- ***The best way to learn is to teach!*** If you can't explain to someone else what you have done, you haven't really understood it! (This is harder than you think!)

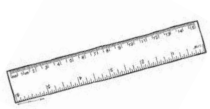


Past Tests and Exams

- The purpose of obtaining and going through old tests and exams is to get to know "the system".
- Each course and prof will have a certain pattern and style. Knowing the pattern in advance gives you an edge.
  - Don't count on lightning to strike twice – memorizing old test questions rarely works!

Aids Allowed on the Final Exam



- Any calculator without communication capability.
- Aid sheet: one single, original, handwritten 8 1/2 × 11 inch sheet of paper, which may be written on both sides.
- A ruler. 
- A **paper** copy of an English translation dictionary.
- Also:

During the Exam

- Exam begins at **7:00pm SHARP**!!! Seating will begin at 6:50pm, pens hit paper at 7:00.
- This exam is run by the faculty, not the physics department, so be extra careful about the rules.
- Skim over the entire exam from front to back **before** you begin. Look for problems that you have confidence to solve first.
- If you start a problem but can't finish it, leave it, make a mark on the edge of the paper beside it, and come back to it after you have solved all the easy problems.
- Quite snacks or drinks are allowed, and recommended by me.

Monday Dec. 10 after 10:00pm, you **must**:

Relax, maybe watch Netflix, go to bed early.

- The evening before a test is NOT the best time to study (it is just the most popular)
- Don't worry – you have been studying since the 1st week of classes!
- You need to **relax** and get your mind **physically** ready to focus on Tuesday

See you at the final!

- If you haven’t done it, please check your utoronto email, respond to the course_evaluations email and evaluate me! The deadline is tomorrow!
- The faculty runs a final exam for this course on Thursday Dec.11 at 7:00pm. See you there!
- Please email me (jharlow@physics.utoronto.ca) with any questions. Keep in touch! It’s been a really fun course for me!