PHY131H1S - Class 24

Today:

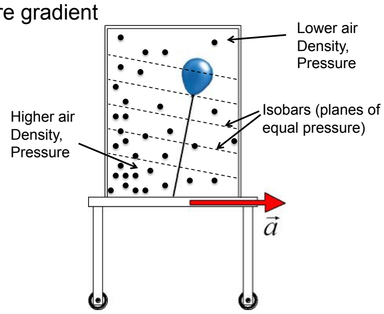
- Course Review!
- The final exam, will be on Dec. 15 at 2pm.
- Note there are no Practicals this week.
- The final exam will cover Chapters 1-15, excluding Chapter 13, and Sections 6.5 and 15.6. The final exam will also cover the Error Analysis Assignment and all the material in it.
- You are allowed ONE double-sided aid-sheet for the final exam, which you must prepare yourself.

Survey Question

- Working through the weekly MasteringPhysics homework assignments has been an effective way for me to learn course material

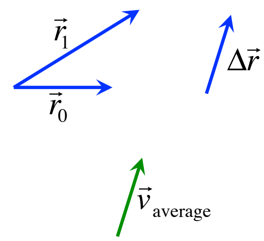
A. Strongly agree
B. agree
C. Neutral
D. Disagree
E. Strongly disagree

Note about Balloon on a cart Demonstration:
As the cart is accelerating to the right, the heavier air molecules are left behind, to the left, creating a tilted pressure gradient



Average Velocity

$$\vec{v}_{\text{average}} = \frac{\vec{r}_1 - \vec{r}_0}{\Delta t} = \frac{\Delta \vec{r}}{\Delta t}$$

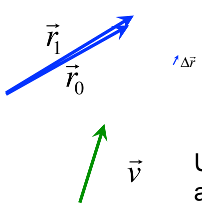


Units of $\Delta \vec{r}$ are metres.

Units of $\vec{v}_{\text{average}}$ are metres per second.

Velocity (a.k.a. "instantaneous velocity")

$$\vec{v} = \lim_{\Delta t \to 0}\left(\frac{\Delta \vec{r}}{\Delta t}\right) = \frac{d\vec{r}}{dt}$$

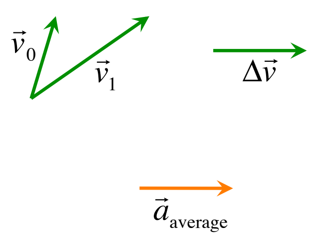


Units of $\Delta \vec{r}$ are metres.

Units of $\vec{v}$ are metres per second.

Average Acceleration

$$\vec{a}_{\text{average}} = \frac{\vec{v}_1 - \vec{v}_0}{\Delta t} = \frac{\Delta \vec{v}}{\Delta t}$$

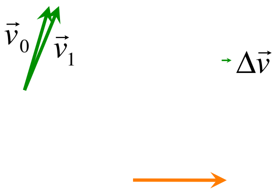


Units of $\Delta \vec{v}$ are m/s.

Units of $\vec{a}_{\text{average}}$ are m/s^2.

Acceleration (a.k.a. “instantaneous acceleration”)

$$\vec{a} = \lim_{\Delta t \to 0}\left(\frac{\Delta \vec{v}}{\Delta t}\right) = \frac{d\vec{v}}{dt}$$



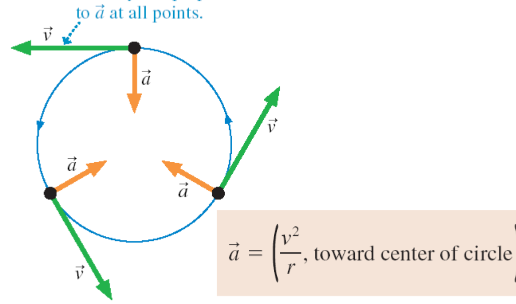
$\vec{v}_0$ $\vec{v}_1$ $\Delta\vec{v}$

Units of $\Delta\vec{v}$ are m/s.

$\vec{a}$

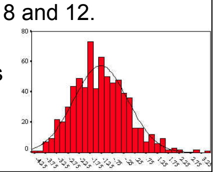
Units of $\vec{a}$ are m/s^2.

FIGURE 4.40 For uniform circular motion, the acceleration $\vec{a}$ always points to the center.



± Errors

- Why are errors so important to scientists and engineers?
- Errors **eliminate** the need to report measurements with vague terms like “approximately” or “≈”.
- Errors give a *quantitative* way of stating your confidence level in your measurement.
- Saying the answer is 10 ± 2 means you are 68% sure that the actual number is between 8 and 12.
- It also implies that you are 95% confident that the actual number is between 6 and 14 (the 2-sigma range).



Propagation of Errors

- Rule #1 (sum or difference rule):
- If $z = x + y$
- or $z = x - y$
- then $\Delta z = \sqrt{\Delta x^2 + \Delta y^2}$

- Rule #2 (product or division rule):
- If $z = xy$
- or $z = x/y$
- then $\frac{\Delta z}{z} = \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2}$

Propagation of Errors

- Rule #2.1 (multiply by exact constant rule):
- If $z = xy$ or $z = x/y$
- and x is an exact number, so that Δx=0
- then $\Delta z = |x|(\Delta y)$

- Rule #3 (exponent rule):
- If $z = x^n$
- then $\frac{\Delta z}{z} = n\frac{\Delta x}{x}$

The Error in the Mean

- Many individual, independent measurements are repeated N times
- Each individual measurement has the same error Δx
- Using error propagation you can show that the error in the estimated mean is:

$$\Delta\bar{x}_{\text{est}} = \frac{\Delta x}{\sqrt{N}}$$

Significant Figures

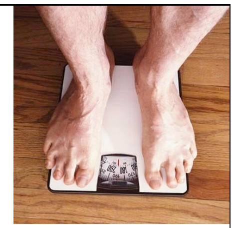
- Discussed in Section 1.9 of Knight Ch.1
- The rules for significant figures when errors are involved are:

1. Errors should be specified to one or two significant figures.

2. The most precise column in the number for the error should also be the most precise column in the number for the value.

- Example: If a calculated result is (7.056 +/- 0.705) m, it is better to report (7.1 +/- 0.7) m.

Weight ≠ Weight ??!?



- Physics textbooks and physics teachers do not all agree on the definition of the word "weight"!
- Sometimes "weight" means the exact same thing as "force of gravity". That is ***not*** how Randall Knight uses the word. (I will follow Knight's definitions.)
- In Knight, "weight" means the magnitude of the *upward* force being used to support an object.
- If the object is at rest or moving at a constant velocity relative to the earth, then the object is in equilibrium. The upward supporting force exactly balances the downward gravitational force, so that weight = mg.

Knight's Definition of weight, page 161:

The **weight** of an object is the reading of a calibrated spring scale on which the object is stationary. Weight is the result of weighing. The weight of an object with vertical acceleration a_y is

$$w = mg\left(1 + \frac{a_y}{g}\right)$$

"Kinetic Friction" $\vec{f}_k$

- Also called "sliding friction"
- When two flat surfaces are in contact and sliding relative to one another, heat is created, so it slows down the motion (kinetic energy is being converted to thermal energy).

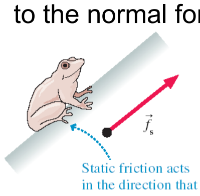
$$f_k = \mu_k n$$

where n is the normal force.

The direction of $\vec{f}_k$ is opposite the direction of motion.

"Static Friction" $\vec{f}_s$

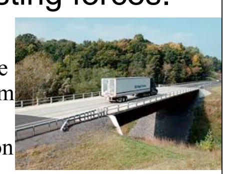
- When two flat surfaces are in contact but are not moving relative to one another, they tend to resist slipping. They have "locked" together. This creates a force perpendicular to the normal force, called static friction.



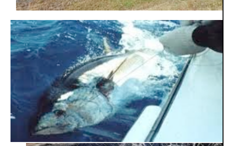
There is no general equation for f_s.

The direction of f_s is whatever is required to prevent slipping.

Limits to the self-adjusting forces.

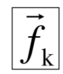


- The normal force of a bridge on a truck is what holds up the truck. If the truck's weight exceeds some maximum value, the bridge will collapse!



- The tension force of a fishing line on a fish is what pulls in the fish. If the fish is too big, the line will break!
- The static friction force is what keeps two surfaces from slipping. If the outside forces are too much, the surfaces will slip!

- In first-year physics, we do not study n_{max} and T_{max}. This is the Physics of Fracture.



Maximum Static Friction

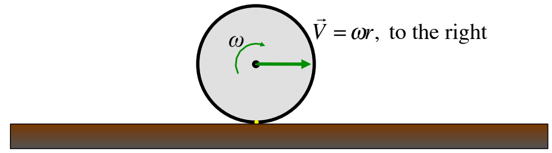
There's a limit to how big f_s can get. If you push hard enough, the object slips and starts to move. In other words, the static friction force has a *maximum* possible size $f_{s\,max}$.

- The two surfaces don't slip against each other as long as $f_s \le f_{s\,max}$.
- A static friction force $f_s > f_{s\,max}$ is not physically possible. Many experiments have shown the following approximate relation usually holds:

$$f_{s\,max} = \mu_s n$$

where n is the magnitude of the normal force, and the proportionality constant μ_s is called the "coefficient of static friction".

Rolling without slipping



The wheel rotates with angular speed ω.

The axle moves with linear speed $v = \omega r$., where r is the radius of the wheel.

Since the bottom point is always at rest, it is *static friction* which acts between the ground and the wheel.

Linear / Rotational Analogy

Linear	Rotational Analogy
$\vec{s}$, $\vec{v}$, $\vec{a}$	θ, ω, α
Force: $\vec{F}$	Torque: τ
Mass: m	Moment of Inertia: I

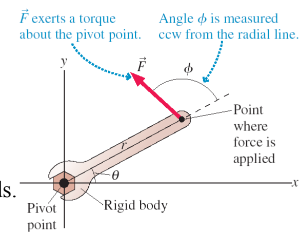
- Newton's 2nd law: $\vec{a} = \dfrac{\vec{F}_{net}}{m}$ $\qquad \alpha = \dfrac{\tau_{net}}{I}$
- Kinetic energy: $K_{cm} = \dfrac{1}{2} m v^2$ $\qquad K_{rot} = \dfrac{1}{2} I \omega^2$
- Momentum: $\vec{p} = m\vec{v}$ $\qquad \vec{L} = I\vec{\omega}$

Torque

Mathematically, we define torque τ (Greek tau) as

$$\tau \equiv rF\sin\phi$$

SI units of torque are N m.
English units are foot-pounds.



Consider a body made of N particles, each of mass m_i, where $i = 1$ to N. Each particle is located a distance r_i from the axis of rotation. We define moment of inertia:

$$I = m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2 + \cdots = \sum_i m_i r_i^2$$

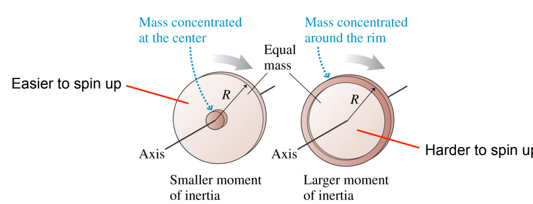
The units of moment of inertia are kg m^2. An object's moment of inertia depends on the axis of rotation.

The moment of inertia

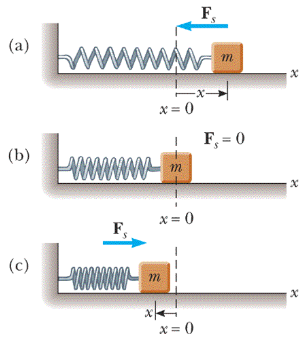
$$I = \sum_i m_i r_i^2 = \int r^2\,dm$$

is the rotational equivalent of mass. The moment of inertia depends on how the mass is distributed around the axis.

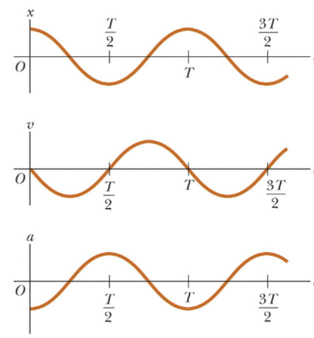
Consequences of Moment of Inertia



Simple Harmonic Motion: Restoring Force provided by Hooke's Law

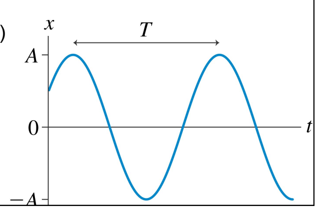


x,v,a for Simple Harmonic Motion



Simple Harmonic Motion notes…

- S.H.M. is *not* constant acceleration, or constant force – both vary with time.
- S.H.M. results when restoring force is proportional to displacement. Other types of oscillatory motion are possible, but not discussed in this course.
- Angular frequency $\omega = 2\pi/T$, where T = period.
- $(T = 2\pi/\omega)$
- "frequency" $f = 1/T$ (in Hertz)



Between now and the Final Exam

- I recommend you be familiar with all Masteringphysics problem sets, the suggested End-Of-Chapter Problems, and all Practicals work.
- Please email me (jharlow @ physics.utoronto.ca) with any questions. Keep in touch! It's been a really fun course for me!