Physics 141.
Review Exam # 1.

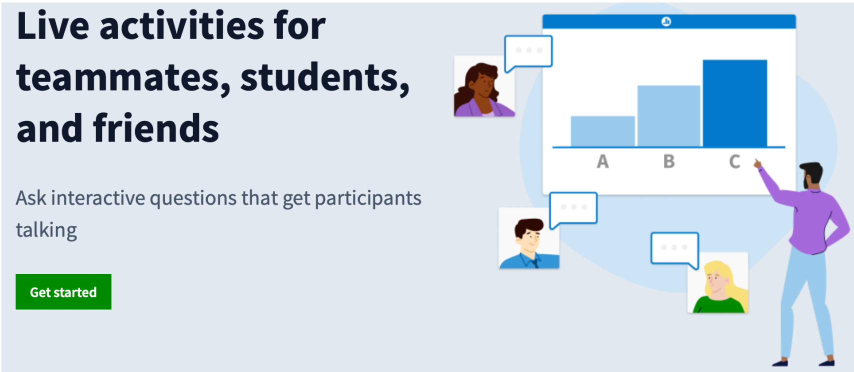
It's all physics!

Physics 141.
Topics for today.

- A quick quiz covering some of the concepts that are important for Exam # 1.
- How to survive Phy 141 exams?
- Review of the material covered on Exam # 1.
    - Error analysis
    - Chapter 1
    - Chapter 2
    - Chapter 3

Quiz lecture 05.
PollEv.com/frankwolfs050

- The quiz today will have three questions.
- I will collect your answers electronically using the Poll Everywhere system.
- The answers for each question will be entered in sequence (first 30 s for question 1, followed by 30 s for question 2, etc.).



Surviving Phy 141 Exams.

- Time your work:
  - Exam has 10 MC + 3 analytical questions.
  - Work 15 minutes on the MC questions.
  - Work 15 minutes on each of the analytical questions (45 minutes total).
  - You now have 20 minutes left to finish those questions you did not finish in the first 15 minutes.
- Write neatly – you cannot earn credit if we cannot read what you wrote!
- Write enough so that we can see your line of thought – you cannot earn credit for what you are thinking!

Surviving Phy 141 Exams.

- Most solutions should start with a diagram, showing all forces (direction and approximate magnitude) and dimensions. All forces and dimensions should be labeled with the variables that will be used in your solution.
- Indicate what variables are known and what variables are unknown.
- Indicate which variable needs to be determined.
- Indicate the principle(s) that you use to solve the problem.
- If you make any approximations, indicate them.
- Check your units!

Preparing for Exam # 1

- Take the practice exam as if it was a real exam: take 80 minutes to complete it. Compare your work to the posted solutions to help you focus on specific areas.

- There will be extra office hours next week on Monday September 16: details to be announced via email.

- Notes:
  - You need a number 2 pencil to complete the multiple-choice part of the exam.
  - You need to know your student ID #.
  - You do NOT need a calculator on the exam.
  - The exam starts at 8 am and ends at 9.20 am.
  - If you are late to start, you will have less time to finish.

Warning.

- I cannot cover everything I discussed in lectures 1 – 5 in this review.
- If I skip over certain topics, it does not mean you should not understand that material.
- Your TAs will not see the exam until you see it.

Review Midterm Exam # 1. Error Analysis.

- Terminology introduced:
  - Statistical and systematic errors.
  - The Gaussian distribution: the centroid (the mean) and the width (the standard deviation).
  - The average:
    - Normal average.
    - Weighted average.
  - The error in the average:
    - The error in the mean.
    - The error of the weighted mean.

Review of Error Analysis.

- Experimental errors are an integral part of the measurement process.
- Systematic errors can in general be reduced or eliminated by using proper tools and procedures.
- Statistical error can not be eliminated. If we repeat the same measurement N times, we will get N different values due random fluctuations that are inherent to the measurement process.
- If we repeat the same measurement N times we expect that each measurement has the same error. We can use the normal mean and the error in the mean to combine the result of these N measurements.
- If we change the conditions of the measurement, then each measurement will have different errors. We need to use the weighted average and its error to combine the result of these N measurements.

Review of Error Analysis. The normal mean and its error.

- The standard deviation is a measure of the error made in each individual measurement.
- Often you want to measure the mean and the error in the mean.
- Which should have a smaller error, an individual measurement or the mean of N measurements?
- The answer ….. the mean, if you do more than one measurement, the error in the mean is equal to:

$$\sigma_m = \frac{\sigma}{\sqrt{N}}$$

Review of Error Analysis. The weighted mean and its error.

- When the data have different errors, we need to use the weighted mean to estimate the mean value.
- This procedure requires you to assign a weight to each data point:

$$w_i = \frac{1}{\sigma_i^{\,2}}$$

- Note: when the error decreases the weight increases.
- The weighted mean and its error are defined as:

$$\bar{y} = \frac{\sum_{i=1}^{N} w_i y_i}{\sum_{i=1}^{N} w_i} \qquad \sigma_y = \sqrt{\frac{1}{\sum_{i=1}^{N} w_i}}$$

Review of Error Analysis. Error propagation.

- Consider that a parameter of interest $f = F(x, y, z, \ldots)$ depends on the measured parameters $x, y, z, \ldots$.

- The error in f, σ_f, depends on the function F, the measured parameters $x, y, z, \ldots$, and their errors, $\sigma_x, \sigma_y, \sigma_z, \ldots$, and can be calculated using the following formula:

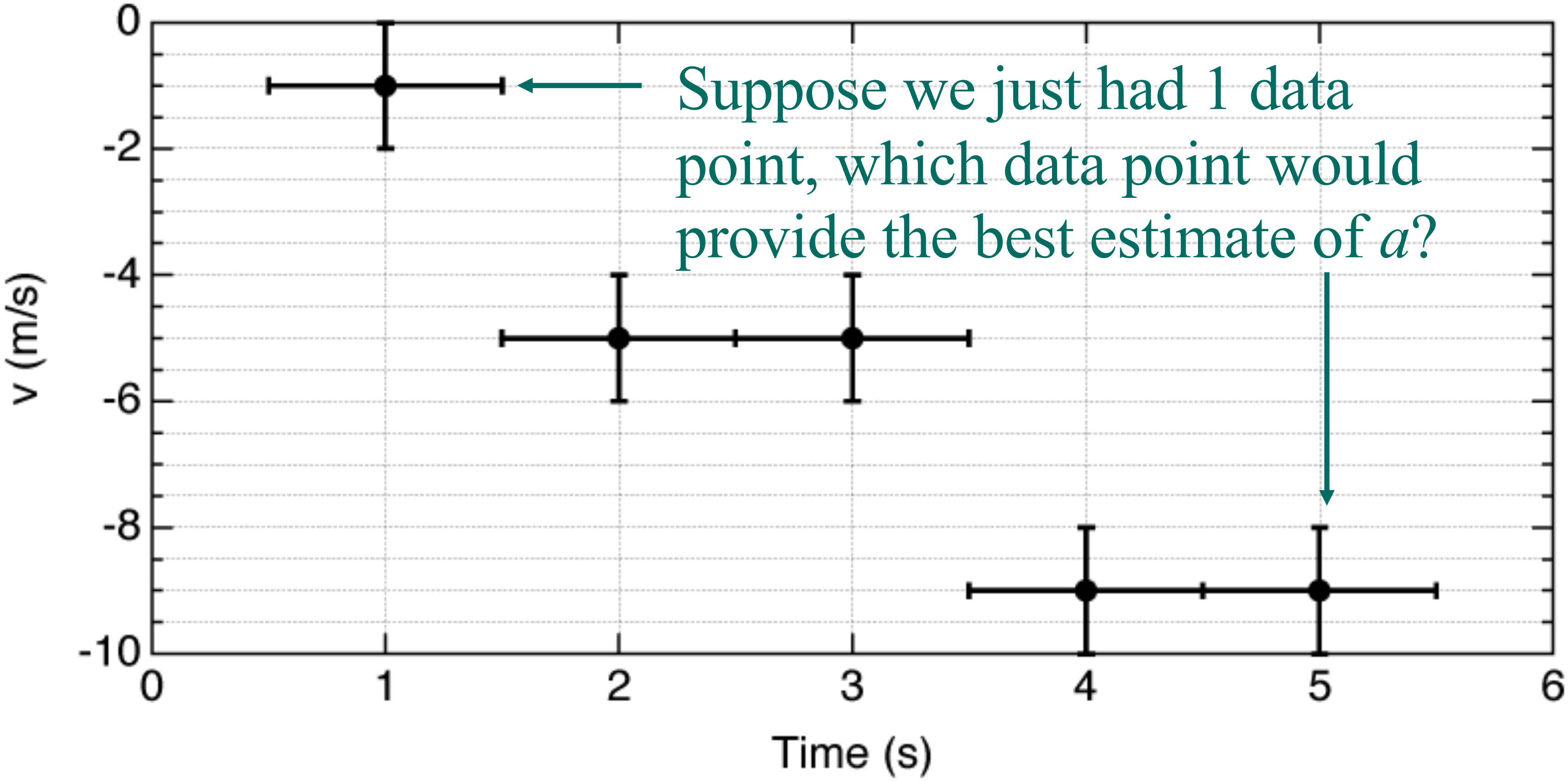
$$\sigma_f = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial F}{\partial y}\right)^2 \sigma_y^2 + \left(\frac{\partial F}{\partial z}\right)^2 \sigma_z^2 + \ldots}$$

Review of Error Analysis.
Error propagation.

If $t = 0$, $v = 0$.

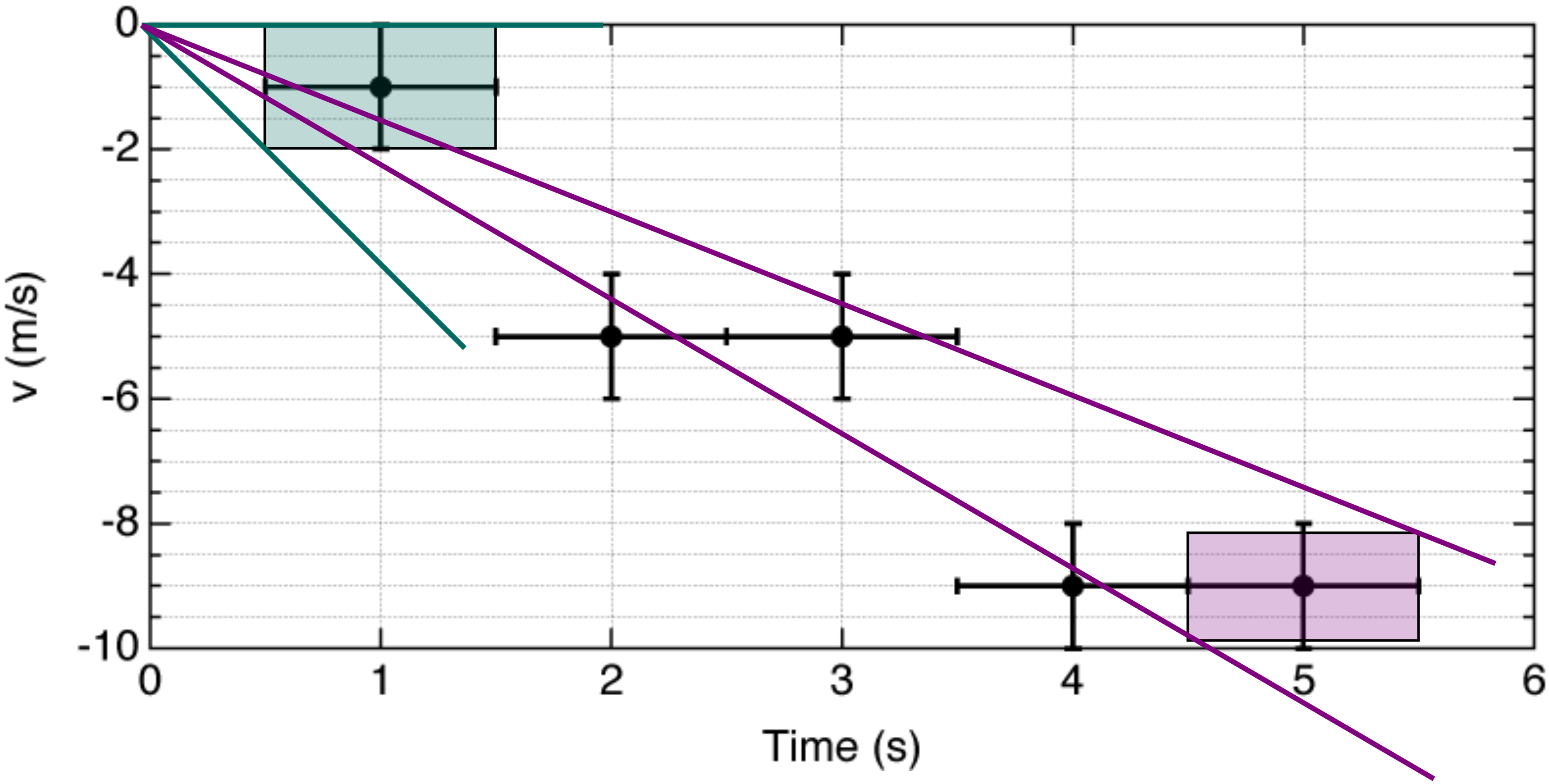
$v = at$: determine a and its error.

Suppose we just had 1 data point, which data point would provide the best estimate of a?



Review of Error Analysis. Error propagation.

$v = at$: determine a and its error.



ANY QUESTIONS ABOUT ERROR ANALYSIS?

Review Midterm Exam # 1.
Chapter 1.

- The focus of this Chapter is an introduction to the matter around us and their interactions.
- The parameters used to describe motion are introduced.
- The linear momentum of a particle is defined and the effect of relativistic velocities is described.
- We discussed how to explore the properties of interactions by looking at changes in the linear momentum of the particles being examined.
- Sections excluded: none (sorry).

Review Midterm Exam # 1.
Chapter 1.

- Terminology introduced:
  - Vectors and their use to describe motion (position, velocity, acceleration).
  - Linear momentum (relativistically correct).
  - Techniques to study the properties of interactions.

Review Chapter 1.
Linear momentum.

- The linear momentum of a particle is defined as:

$$\vec{p} = \frac{m\vec{v}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where v is the velocity and m is the rest-mass of the particle.

- At low velocities, $v \ll c$, the definition of the linear momentum of the particle approaches the definition you should have seen in your high-school physics course:

$$\vec{p} = \frac{m\vec{v}}{\sqrt{1 - \frac{v^2}{c^2}}} \approx m\vec{v} \text{ (if } v \ll c)$$

Review Chapter 1.
Predicting motion.

- If we know the interaction acting on our particle and the time over which this interaction is acting, we can determine the change in the linear momentum of our particle:

$$\vec{p}_{new} = \vec{p}_{old} + \Delta\vec{p}$$

- The new position of our particle can be found if we know its velocity:

$$\vec{r}_{new} = \vec{r}_{old} + \vec{v}\Delta t$$

$$\vec{r}_{new} = \vec{r}_{old} + \frac{1}{\sqrt{1+\left(\frac{p_{old}}{mc}\right)^2}}\frac{\vec{p}_{old}}{m}\Delta t \approx \vec{r}_{old} + \frac{\vec{p}_{old}}{m}\Delta t$$

Low velocities

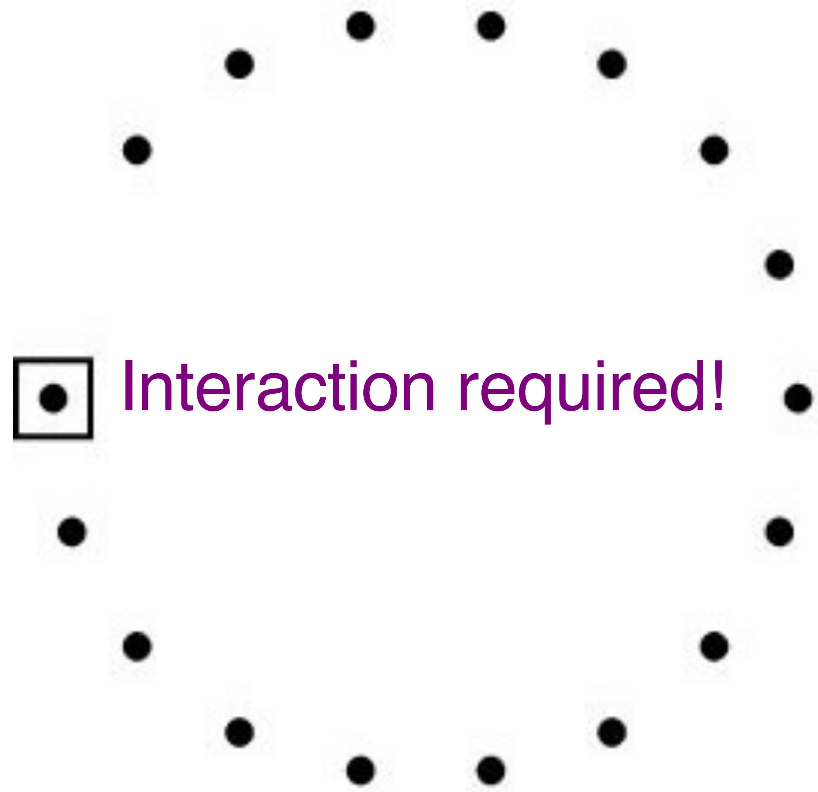
Review Chapter 1.
Probing interactions.

- Effect of an interaction:

  change in the magnitude of the linear momentum

  and/or

  change in the direction of the linear momentum.



ANY QUESTIONS ABOUT CHAPTER 1?

Review Midterm Exam # 1. Chapter 2.

- The focus of this Chapter is the connection between the interactions between a system and its surroundings and the linear momentum of the system.

- We introduced the momentum principle, which relates the change in the momentum of the system to the force and the time during which this force is acting.

- We showed how the momentum principle can be used to study the time evolution of a system. We explored how to use this principle both in the relativistic limit and in the low-velocity limit.

- Sections excluded: none (sorry).

Review Midterm Exam # 1. Chapter 2.

- Terminology introduced:
  - The momentum principle.
  - The net force.
  - The impulse of a force.
  - Equations of motion associated with constant forces.
  - Conservation of linear momentum.

Review Chapter 2.
The momentum principle.

- The change in the linear momentum of an object is proportional to the strength of the interaction and to the duration of the interaction. This principle is known as the **momentum principle**:

$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

- This equation allows us to calculate the time-dependence of the linear momentum if we know the initial value and the time/position dependence of the interaction.

Review Chapter 2.
Quantifying the extent of an interaction.

- If we do not know the interaction, but we measure the change in the linear momentum we can determine extent of the interaction:

$$\vec{F}_{net} = \frac{d\vec{p}}{dt}$$

- In the non-relativistic limit this relation becomes

$$\vec{F}_{net} = \frac{d\vec{p}}{dt} \approx m\frac{d\vec{v}}{dt} = m\vec{a}$$

- If the net force acting on a system is zero, the change in its linear momentum will be zero, and linear momentum will be conserved.

Review Chapter 2.
Linear motion in one dimension.

Parameters define initial conditions!

$$x(t) \qquad x(t) = \int_{t_0}^{t} v(t')dt' \qquad x(t) = x_0 + v_0 t + \frac{1}{2}at^2$$

$$v(t) = \frac{dx}{dt} \qquad v(t) = \int_{t_0}^{t} a(t')dt' \qquad v(t) = v_0 + at$$

$$a(t) = \frac{dv}{dt} = \frac{d^2x}{dt^2} \qquad a(t) \qquad a(t) = a = \text{ constant}$$

The same for different observers!

Review Chapter 2.
Motion in three dimensions: constant a.

$$\vec{r}(t) = \begin{pmatrix} x(t) \\ y(t) \\ z(t) \end{pmatrix} \quad \vec{v}(t) = \begin{pmatrix} v_x(t) \\ v_y(t) \\ v_z(t) \end{pmatrix} \quad \vec{a}(t) = \begin{pmatrix} a_x(t) \\ a_y(t) \\ a_z(t) \end{pmatrix}$$

where

$$x(t) = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 \quad v_x(t) = v_{0x} + a_x t \quad a_x = \text{constant}$$

$$\mathrm{y}(t) = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 \quad v_y(t) = v_{0y} + a_y t \quad a_y = \text{constant}$$

$$\mathrm{z}(t) = z_0 + v_{0z}t + \frac{1}{2}a_z t^2 \quad v_z(t) = v_{0z} + a_z t \quad a_z = \text{constant}$$

Review Chapter 2.
A special case: projectile motion in 2D.

$$x(t) = x_0 + v_{0x}t \qquad y(t) = y_0 + v_{0y}t - \frac{1}{2}gt^2$$

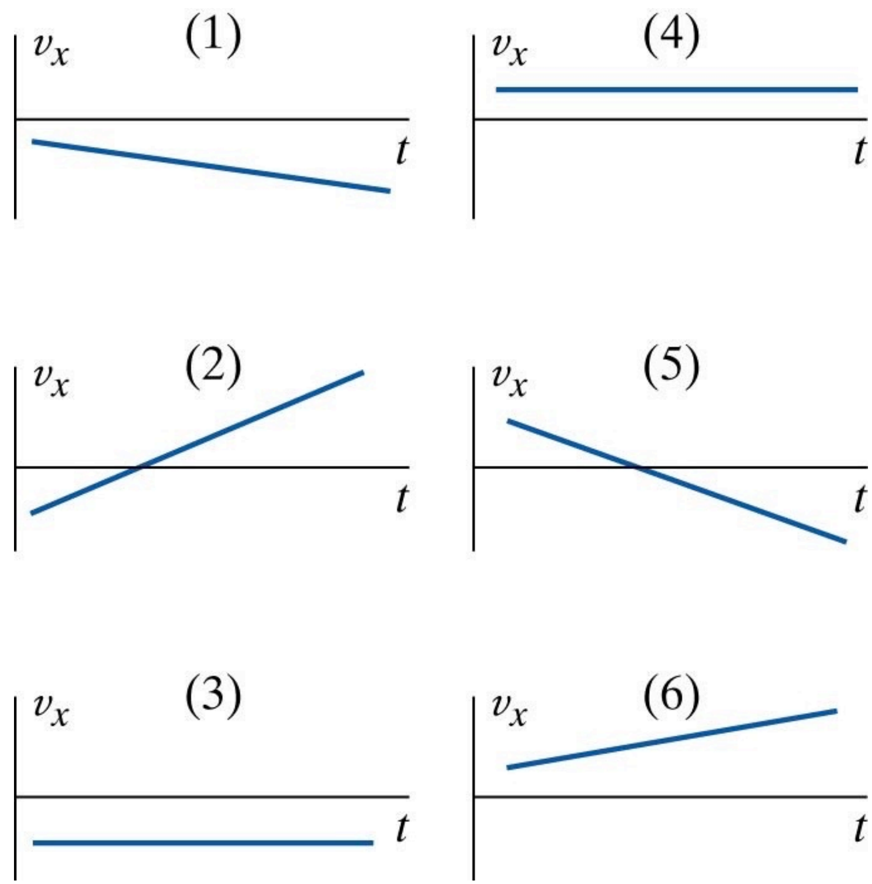
$$v_x(t) = v_{0x} = \text{constant} \qquad v_y(t) = v_{0y} - gt$$

$$a_x(t) = 0 \qquad a_y(t) = -g = \text{constant}$$

Note: The non-zero gravitational acceleration only affects motion in the vertical direction; not in the horizontal direction.

Review Chapter 2.
Understanding graphs.

- Make sure you understand what information you can obtained from graphs showing velocity or position as function of time.
  - The slope of the position vs time graph is the velocity.
  - The slope of the velocity vs time graph is the acceleration.
  - The sign of position and velocity is important.



Review Chapter 2.
Sample problem: P36.

2.P.59 A small dense ball with mass 1.5 kg is thrown with initial velocity $\langle 5, 8, 0 \rangle$ m/s at time $t = 0$ at a location we choose to call the origin ($\langle 0, 0, 0 \rangle$ m). Air resistance is negligible.

(a) When the ball reaches its maximum height, what is its velocity (a vector)? It may help to make a simple diagram.

(b) When the ball reaches its maximum height, what is t? You know how v_y depends on t, and you know the initial and final velocities.

(c) Between the launch at $t = 0$ and the time when the ball reaches its maximum height, what is the average velocity (a vector)? You know how to determine average velocity when velocity changes at a constant rate.

(d) When the ball reaches its maximum height, what is its location (a vector)? You know how average velocity and displacement are related.

Review Chapter 2.
Sample problem.

(e) At a later time the ball's height y has returned to zero, which means that the average value of v_y from $t = 0$ to this time is zero. At this instant, what is the time t?

(f) At the time calculated in part (e), when the ball's height y returns to zero, what is x? (This is called the "range" of the trajectory.)

(g) At the time calculated in part (e), when the ball's height y returns to zero, what is v_y?

(h) What was the angle to the x axis of the initial velocity?

(i) What was the angle to the x axis of the velocity at the time calculated in part (e), when the ball's height y returned to zero?

ANY QUESTIONS ABOUT CHAPTER 2?

Review Midterm Exam # 1.
Chapter 3.

- The focus of this Chapter is the study of motion induced by external forces.

- The primary force on which the Chapter focuses is the gravitational force. Other forces, such as the electric force and the spring force, are briefly described.

- The four fundamental interactions and their relative strengths are introduced in this Chapter.

- The different types of motion discussed in this Chapter include orbital motion and chaos.

- Sections excluded: none (sorry).

Review Midterm Exam # 1.
Chapter 3.

- Terminology introduced:
    - Newton's laws of motion.
    - The four fundamental interactions.
    - The gravitational force law.
    - The Shell theorem.
    - Mass and weight.
    - The principle of superposition.
    - Orbital motion.

Review Chapter 3.
The four fundamental interactions.

For PHY 141: Know the order of the strength of these forces.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
Strength relative to electromag for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

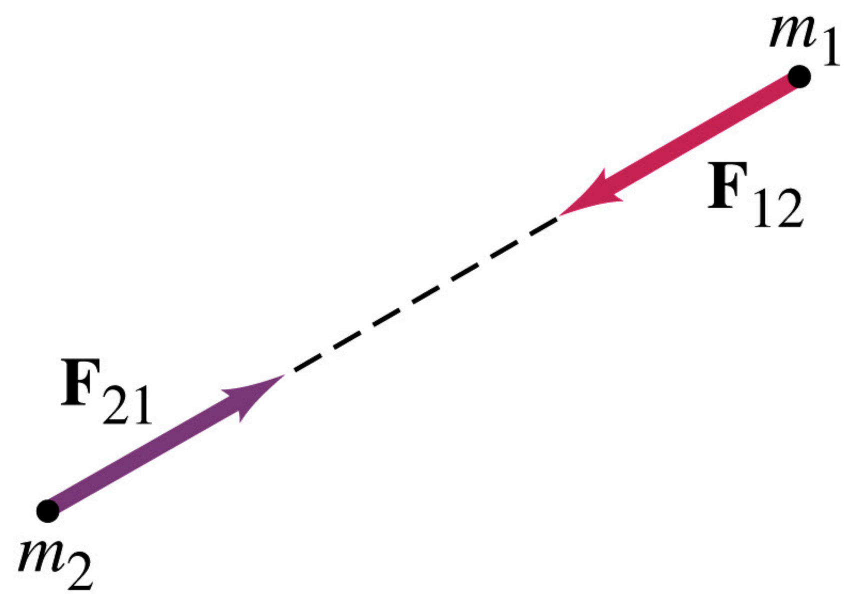
http://particleadventure.org/particleadventure/frameless/chart.html

Review Chapter 3.
The gravitational force.

- The gravitational force is given by the following relation:

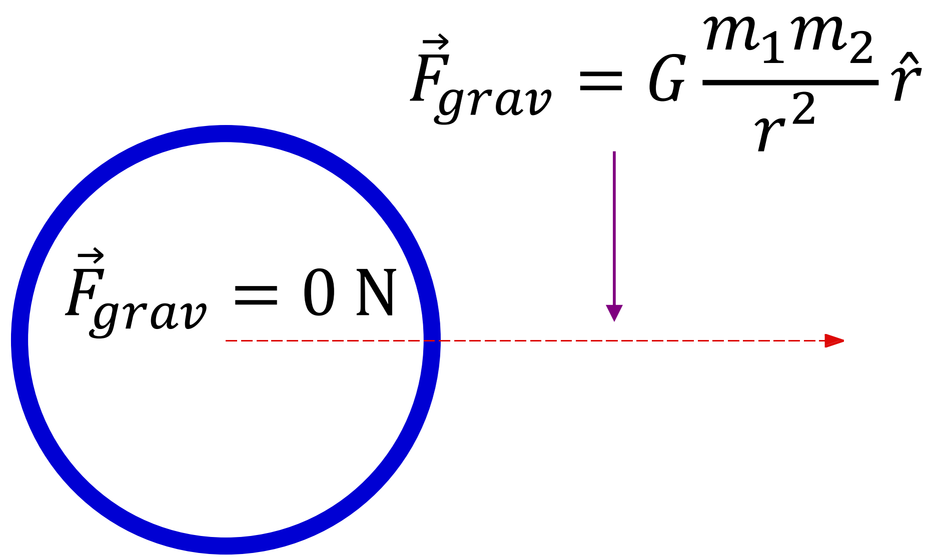
$$\vec{F}_{grav} = G\frac{m_1 m_2}{r_{12}^2}\hat{r}$$

- The constant G is the gravitational constant which is measured to be 6.67 x 10^{-11} Nm^2/kg^2.
- Note: the gravitational force does not depend on the momentum of the particles.



Review Chapter 3.
The shell theorem.

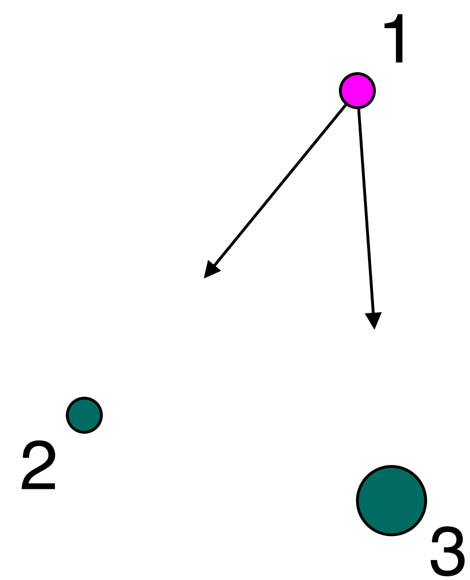
- Consider a shell of material of mass m_1 and radius R.
- In the region outside the shell, the gravitational force on a point mass m_2 will be identical to what it would have been if all the mass of the shell was located at its center.
- In the region inside the shell, the gravitational force on a point mass m_2 is equal to 0 N.



Review Chapter 3.
The superposition principle.

If several forces are acting on our object, we can use the **Superposition Principle** to determine the net force acting on our object:

> The net force on an object is the vector sum of the individual forces acting on it by other objects. Each individual interaction is unaffected by the presence of other interacting objects.



Review Chapter 3.
An application of the superposition principle.

webwork / phy141f23 / 02 / 4

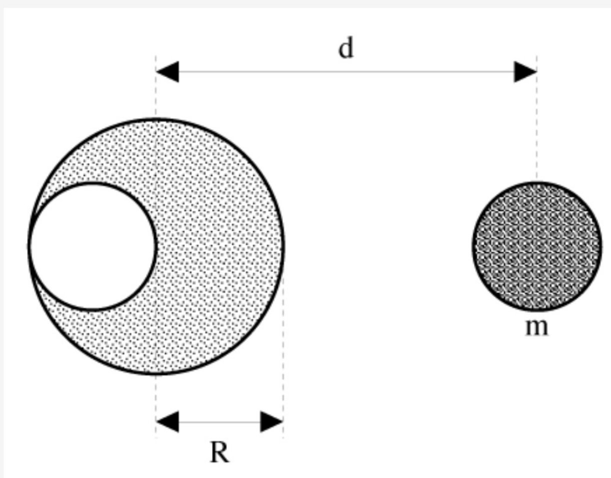
02: Problem 4

(25 points) library/type29/prob19.pg

Previous Problem | Problem List | Next Problem

This set is **visible to students.**

A spherical hollow is made in a sphere of radius R = 13.1 cm such that its surface touches the outside surface of the sphere and passes through its center (see Figure). The mass of the sphere before hollowing was M = 66.0 kg. What is the magnitude of the gravitational force between the hollowed-out lead sphere and a small sphere of mass m = 3.8 kg, located a distance d = 0.97 m from the center of the lead sphere?



Review Chapter 3.
Quantifying the extent of an interaction.

- If our system contains multiple particles:
  - We need to consider multiple forces acting on these particles (internal and external forces).
  - The results of these forces will be changes in the linear momenta of these particles.
  - **The total linear momentum of this system of particles will be the vector sum of the linear momenta associated with each particle**.
  - The net force is the vector sum of the forces acting on each particle. Due to Newton's third law, the internal forces cancel, and **the net force is equal to the vector sum of the external forces**.
  - If the sum of all the external force is equal to zero, then the net force on the system will be zero and the change in the linear momentum will be zero. In that case, **linear momentum will be conserved**.

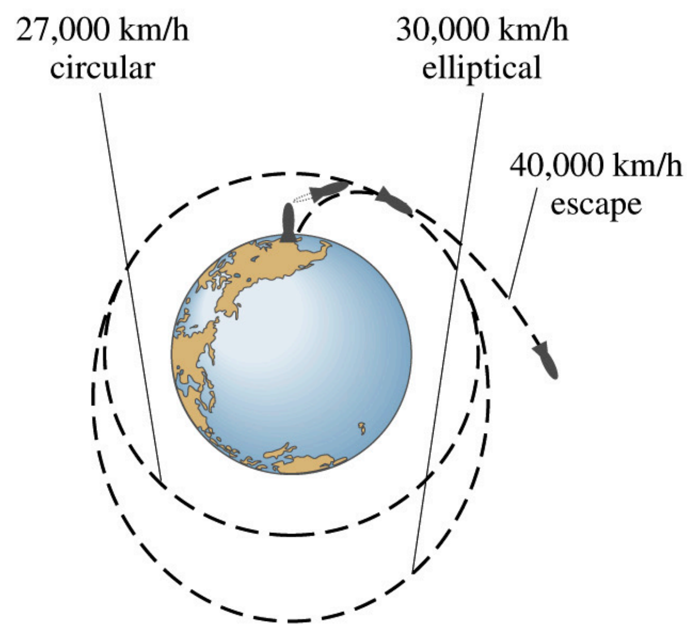
Review Chapter 3.
Multi-particle system: orbital motion.

- In order for an object of mass m to be in a circular orbit of radius r, a net force must be acting on it with a magnitude of mv^2/r, directed towards the center of the earth.
- The only force that acts in this direction is the gravitational force.
- The orbital velocity must satisfy the following relation

$$v^2 = GM_{\text{earth}}/r$$

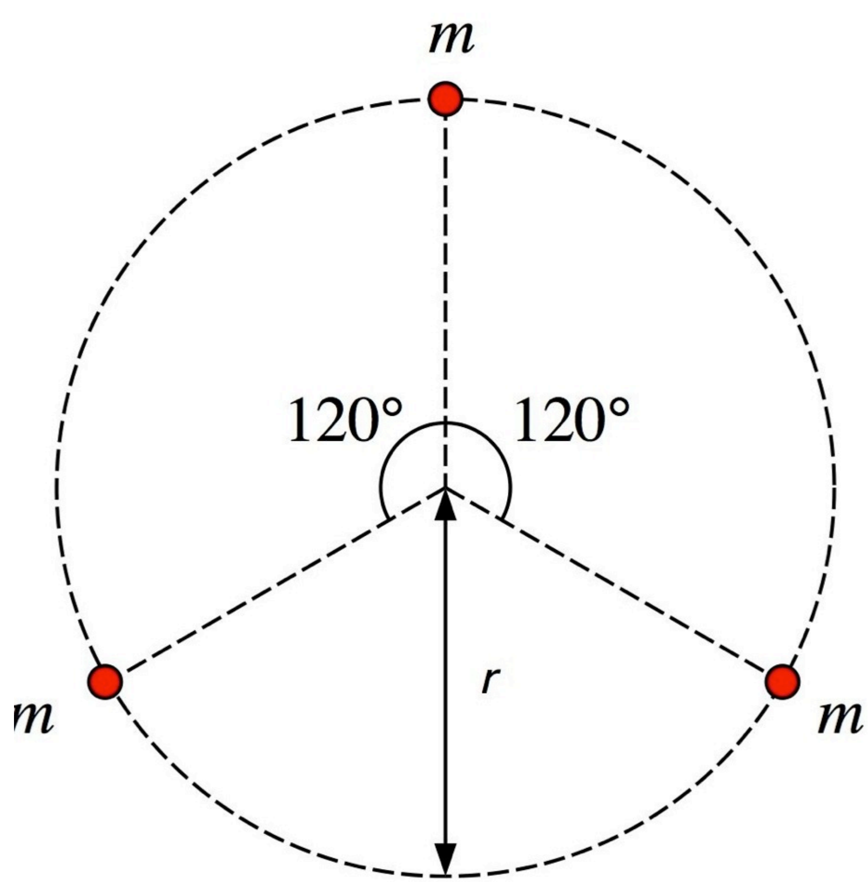
- This relation can be rewritten in terms of the orbital period:

$$r^3 = GM_{\text{earth}}T^2/4\pi^2$$



Review Chapter 3. Orbital motion.

- Remarks:
  - Orbital motion requires that the net force on each mass is directed towards the center of the orbit.
  - No mass needs to be located at the center of the orbit.
  - Calculating the net force requires vector addition of the individual forces.



Review Chapter 3.
Sample problem: P25.

3.P.40 A steel ball of mass m falls from a height h onto a scale calibrated in newtons. The ball rebounds repeatedly to nearly the same height h. The scale is sluggish in its response to the intermittent hits and displays an *average* force F_{avg}, such that $F_{avg}T = F\Delta t$, where $F\Delta t$ is the brief impulse that the ball imparts to the scale on every hit, and T is the time between hits.

Calculate this average force in terms of m, h, and physical constants. Compare your result with what the scale reads if the ball merely rests on the scale. Explain your analysis carefully (but briefly).

ANY QUESTIONS ABOUT CHAPTER 3?

The end!

Good luck preparing for Exam # 1.