Classical Physics I

PHY141
Lecture 1
Introduction to PHY141, Units, Vectors, Math Tools, ...
PHY131 Spring 2009

- Information on Course pages:
  - Black Board: PHY141 Fall 2014
- Will be available online: schedule, syllabus, Lab and Recitation section, Exams, Grades, etc.

- Required:
    - Buy also the www.MasteringPhysics.com access key for Online Homework
    - valid for 3 semesters...
  - RF Clicker (Bookstore or TurningTechnologies.com)
    - Stony Brook standard - can be used for other courses
    - register your clicker on Blackboard within 14 days.
    - Register your clicker on Blackboard to see your grades!
  - Scientific Calculator (Trig functions, exponentiation, roots, logarithms)
  - Laboratory Note Book (for Lab)
  - Internet Access (e.g. in the Help Room Physics A-117)
PHY141 – Put in the necessary work!

• You can be successful If:
  - you do (and understand) ALL HOMEWORK
  - read and understand ALL material

• Thus, requirements are:
  - discipline
  - Time and perseverance...
  - picturing the situations
  - Common sense (does your result make sense?)
  - logical reasoning...
  - Mathematics: equations, differentiation, and integration

• Large Pay-off:
  - can use physics approach everywhere: CompSci, Engin.,
  Finance, Medicine & other sciences, Wall St., ...
  - builds confidence, employability, ...
Practical Information

• Grades will be available online

• Grading:

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<thead>
<tr>
<th>Component</th>
<th>Relative Weight</th>
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<tbody>
<tr>
<td>Midterm I</td>
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<td>Midterm II</td>
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<td>Final</td>
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<tr>
<td>Recitation + Web HW</td>
<td>15%</td>
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<tr>
<td>Lecture Quizzes (Clickers)</td>
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• Homework:
  - assigned every week, assignment is found on BB
  - Homework is meant to prepare for exams and HW grade is therefore NOT related to the time spent on doing problems ...
  - do NOT search HW solutions elsewhere without trying to solve the problem seriously by yourself!
  - HW Help: Physics Help Room (A-level), or PHY141 Blog, or Instructor Office Hours (TBA)
Physics – What is it about?

• Physics is the study of the universe to discover its underlying regularity, symmetry, and predictability
  - Making sense of what we observe...
  - use models and current understanding to make pre-/postdictions
  - use experimentation to test and obtain new insights and directions
  - NOT a system of “beliefs” but of rational deductions and inductions...
    “believing” in physics is an oxymoron!

• Tools: Logical reasoning, Math, Common sense, experimentation, ...

• Sir Ernest Rutherford:
  "All science is either physics or stamp collecting."

Sir Ernest Rutherford (1871-1937)
Goals of this Course

• **Overview of Classical Physics**
  - **Part I - Mechanics:**
    - finding the motion $x(t)$ of things (objects, fluids, gases)
  - The Physics from Galileo and Newton till Einstein and Planck ("Modern Physics")
    - many centuries of discoveries and understanding crammed into one semester!
    - *modern physics is a numerically* a “small correction” to everyday phenomena, but a big leap in understanding...

• **More generally (and useful beyond physics!):**
  - Learn to solve problems rationally
  - learn to reason and draw conclusions
  - learn to make quick estimates (including uncertainties!)
  - add mathematics to your toolbox!
  - Hence, physics is used as a “cut-off” course in many science programs!
Units in Physics

- Units
  - see the tables in the book on the Metric SI system (mks system):
    - m(eter), kg(kilogram), s(econd), A(mpere), K(elvin), cd(candela)
  - use PREFIXes to indicate power-of-ten:
    - lower case for -ve powers: d(eci)=-1 ,c(enti)=-2 ,m(ili)=-3 ,μ(icro)=-6, n(ano)=-9, p(ico)=-12, f(emto)=-15,…
    - UPPER case for +ve powers:  M(ega)=+6, G(iga)=+9, T(era)=+12, …
    - EXCEPTION: k(ilo)=+3
  - conversions:
    - use the unit equations: 1 mi = 1.61 km = 1610 m, etc.
    - e.g:
      \[
      55 \text{ mi/hr} = 55 \frac{\text{mi}}{\text{hr}} = 55 \frac{1.61 \text{ km}}{3600 \text{ s}} = 55 \frac{1610 \text{ m}}{3600 \text{ s}} = 24.6 \frac{\text{m}}{\text{s}}
      \]
    - use units to your advantage to check results; e.g.
      \[
      \text{period } T = \sqrt{ \frac{L \text{ (length of the pendulum)}}{g \text{ (constant of gravitational acceleration)}} \frac{\text{m}}{\text{m/s}^2}} \Rightarrow \text{unit of } T: \text{ s}
      \]
  - Thus: Keep symbols as long as reasonably possible in your calculations: put the numbers in only last…
Definitions and “Laws”

• Many physics quantities will be defined in this course...
  - not enough characters in roman and greek alphabets to have unique symbols for everything...
  - Symbols may vary according to author and book... but must be defined in beginning if not universally accepted... (also by YOU!)
  - Symbols (e.g. $T$) may represent different quantities, depending on the CONTEXT:
    • e.g. $T =$ Tension, or $T =$ time Period, or $T =$ Temperature!
    • if NOT obvious from context: define!
  - Note: some symbols are “reserved” for universal constants: $e$, $g$, $G$, ...
  - Examples of definitions:
    • definition of symbol in terms of language only:
      \[ \text{position-as-function-of-time} \equiv x(t) \]
    • definition of symbol in terms of other symbols: speed $\equiv v \equiv \frac{dx}{dt}$

• Beware: Notation is important:
  - Boldface characters normally represent VECTORS ($\mathbf{F}$, $\mathbf{A}$)
  - italic characters often represent SCALAR variables ($x$, $t$, $F =$ magnitude of $\mathbf{F}$!)

25 Aug 2014
Definitions and “Laws”

• Although many definitions and concepts will be introduced (~2 per lecture), much fewer “Laws” will be given.

• a “Law” is a non-trivial relationship between physical parameters; i.e. a relationship not immediately following from definitions.
  - a Law often is experimentally deduced and later “explained” by an underlying theory...

• the law that concerns us most in this semester is:
  \[ \mathbf{F}_{\text{net}} = m \mathbf{a}, \text{ or better still: } \mathbf{F}_{\text{net}} = \frac{dp}{dt}, \text{ with } \mathbf{p} = mv. \]
  - the net force \( \mathbf{F} \) on an object is proportional to its resulting acceleration \( \mathbf{a} \), with proportionality factor mass \( m \)

• many other laws follow from this one (momentum conservation, energy conservation, ...)

25 Aug 2014
Tools: Vectors and Trigonometry

- Vectors (IMPORTANT!)
  - VECTOR: A quantity that has both a magnitude and a direction
  - examples: displacement, velocity, force, ...
  - compare to SCALAR (=non-directional) quantities: distance, speed, work, volume, ...

- Need an Agreed-Upon Reference System
  - graphical:

- using it:
  - polar coordinates: \( \mathbf{A} = (A, \phi) = (\text{length } A, \text{ azimuth } \phi) \)
  - orthogonal coordinates: \( \mathbf{A} = (A_x, A_y) \)
    in terms of unit vectors:
    \[
    \mathbf{A} = A_x \hat{i} + A_y \hat{j}
    \]
  - Coordinate transformations:
    \[
    \begin{align*}
      A_x &= A \cos \phi \\
      A_y &= A \sin \phi
    \end{align*}
    \]
    \[
    \begin{align*}
      A &= \sqrt{A_x^2 + A_y^2} \\
      \tan \phi &= \frac{A_y}{A_x} \Rightarrow \phi &= \arctan \left( \frac{A_y}{A_x} \right)
    \end{align*}
    \]
Vectors …

• Inverse of a vector \( \mathbf{A} \): \(-\mathbf{A}\)
  - components: \(-A_x, -A_y\)

• Vector Addition: \( \mathbf{R} = \mathbf{A} + \mathbf{B} \)
  - Graphically: add vectors “head-to-toe”

  - using (orthogonal) coordinates:
    • \( R_x = (A+B)_x = A_x + B_x \)
    • \( R_y = (A+B)_y = A_y + B_y \)

  - easily expandable:
    • \( \mathbf{R} = \mathbf{A} + \mathbf{B} + \mathbf{C} + \ldots \)
    • Subtraction = addition of inverse of vector:
      \( \mathbf{R} = \mathbf{A} - \mathbf{B} = \mathbf{A} + (-\mathbf{B}) \)
    • From 2 to 3 dimensions: \( z \)-coordinates...
Vector Dot-Product

- **Dot-Product (Scalar Product)** of two Vectors:
  - \( \mathbf{A} \cdot \mathbf{B} \equiv A_x B_x + A_y B_y + \ldots \)
  - \( = AB\cos\phi = A(B\cos\phi) = B(A\cos\phi) \)
  - result is a SCALAR, i.e. a quantity with magnitude but NO direction!

- Note: two vectors are perpendicular (i.e. \( \phi = 90^\circ \)) when their dot-product is zero!

- Examples: Work (=Force \cdot distance): \( W \equiv \int_{\text{path}} \mathbf{F} \cdot d\mathbf{x} \)

- A second type of product, the **Cross-Product (Vector Product)**, will be discussed later, when we need it...
Differentiation is calculating the limiting value of a ratio of two small numbers:

- Differentiating a function of $x$, $f(x)$, with respect to $x$, i.e. $df(x)/dx$, is calculating the ratio of $df = f(x+dx) - f(x)$ and $(x+dx) - x = dx$, and then taking the limit $dx \to 0$; note: $f$ is calculated around a specific value $x$.

- This ratio can be calculated for any $x$; the ratio itself may depend on $x$.

- **Graphically**, this is equivalent to evaluating the SLOPE of the function $f(x)$ at the ordinate point $x$.

- Let's see this graphically; assume that we want to calculate the differential $df(x)/dx$ at position $x=x_0$; notation $\left. \frac{df(x)}{dx} \right|_{x=x_0}$.

- It is clear that when $dx \to 0$, the ratio $df(x)/dx$ approaches the SLOPE of $f$ at $x=x_0$.
Differentiation

example:

- Consider a graph of position $x$ versus time $t$: $x(t)$, the “motion”
  
  • This graph tells us that the object moves from position 0 (at the origin) up, then is stationary for a period, and then moves back some distance towards the origin ...

- The velocity (also a function of time $t$) is the ratio $dx/dt$, i.e. the slope of $x(t)$ for all values of $t$:

\[
\frac{dx}{dt} \equiv \lim_{x \to 0} \frac{x(t) - x(t+dt)}{dt}
\]

Motion (top plot) $\equiv x(t)$

Velocity (bottom plot):

\[
v(t) \equiv \frac{dx(t)}{dt} \equiv \lim_{x \to 0} \frac{x(t) - x(t+dt)}{dt}
\]

Acceleration (not shown):

\[
a(t) \equiv \frac{dv(t)}{dt} \equiv \lim_{x \to 0} \frac{v(t) - v(t+dt)}{dt}
\]
Examples: \( f(x) = ax^n, \sin(x), \ldots \)

- **addition:** \( f(x) = g(x) + h(x) \):

\[
\frac{df}{dx} \equiv \lim_{dx \to 0} \frac{g(x + dx) - g(x) + h(x + dx) - h(x)}{dx} = \frac{dg}{dx} + \frac{dh}{dx}
\]

- **Inverse:** \( f(x) = \frac{1}{g(x)} \):

\[
\frac{df}{dx} \equiv \lim_{dx \to 0} \frac{\left(\frac{1}{g(x + dx)} - \frac{1}{g(x)}\right)}{dx} = \lim_{dx \to 0} \frac{\left(\frac{g(x) - g(x + dx)}{g(x)g(x + dx)}\right)}{dx} = \lim_{dx \to 0} \frac{\left(\frac{g(x) - g(x + dx)}{g(x)g(x + dx)}\right)}{dx} = -\frac{1}{g^2} \frac{dg}{dx}
\]

- \( f(x) = ax^n \):

\[
\frac{df}{dx} \equiv \lim_{dx \to 0} \frac{a(x + dx)^n - ax^n}{dx} = \lim_{dx \to 0} \frac{a(x^n + nx^{n-1}dx + n(n-1)x^{n-2}(dx)^2 + \ldots) - ax}{dx}
\]

\[
= \lim_{dx \to 0} \frac{a(nx^{n-1}dx + n(n-1)x^{n-2}(dx)^2 + \ldots)}{dx} = \lim_{dx \to 0} an(x^{n-1} + (n-1)x^{n-2}dx + \ldots) = anx^{n-1}
\]

- \( f(x) = \sin x \):

\[
\frac{df}{dx} \equiv \lim_{dx \to 0} \frac{\sin(x + dx) - \sin x}{dx} = \lim_{dx \to 0} \frac{(\sin x \cos dx + \cos x \sin dx) - \sin x}{dx}
\]

\[
= \lim_{dx \to 0} \frac{(\sin x \times 1 + \cos x \times dx) - \sin x}{dx} = \cos x
\]
Examples: $f(x) = \ln(x)$, …

- $f(x) = \ln(x)$:

\[
\frac{df(x)}{dx} \equiv \lim_{dx \to 0} \frac{\ln(x + dx) - \ln(x)}{dx} = \lim_{dx \to 0} \frac{\ln(x + dx)}{dx} = \lim_{dx \to 0} \frac{\ln(1 + dx/x)}{dx} = \frac{\ln(1) + dx/x}{dx} = \frac{1}{x}
\]
Lecture 1

Tools: Integration:

• Integration. We will not treat integration properly here, because that is a topic for the Math course.

• We will start with a definition:

\[ \int_{x_1}^{x_2} dx = \int_{x_1}^{x_2} dF(x) \equiv \{ \text{Area of rectangle of height } \Delta y = 1 \text{ and width } \Delta x = x_1 - x_0 \} = \Delta y \times \Delta x = x_1 - x_0 \]

• Then:

\[ \int_{x_1}^{x_2} f(x) \, dx = \int_{x_1}^{x_2} \frac{dF(x)}{dx} \, dx = \int_{x_1}^{x_2} \frac{dF(x)}{dx} \, dx = \int_{x_1}^{x_2} dF(x) = F(x_2) - F(x_1) \]

where the function \( F(x) \) is defined by \( dF(x)/dx = f(x) \). \( F(x) \) is called the “primitive” of \( f(x) \); it is like a “reverse differentiation”!

• Thus, integration of \( f(x) \) boils down to finding the primitive \( F(x) \) of \( f(x) \): i.e. find \( F(x) \) such that its derivative w.r.t. \( x \) gives \( f(x) \).

• Example:

\[ \int_{x_1}^{x_2} ax^p \, dx = ? \quad \Rightarrow F(x) = ? = \frac{ax^{p+1}}{p+1} \quad (p \neq -1!!) \]

\[ \Rightarrow \int_{x_1}^{x_2} ax^p \, dx = \int_{x_1}^{x_2} \frac{d}{dx}(\frac{ax^{p+1}}{p+1}) \, dx = \int_{x_1}^{x_2} d\left(\frac{ax^{p+1}}{p+1}\right) = \left[\frac{ax^{p+1}}{p+1}\right]_{x_1}^{x_2} = \frac{ax_2^{p+1}}{p+1} - \frac{ax_1^{p+1}}{p+1} \]
Integration Examples:

• what about \( p = -1 \); e.g. \( f(x) = ax^{-1} \) ?

• \( \int_{x_1}^{x_2} x^{-1} \, dx = ? \) \( \Rightarrow F(x) = ? = \ln(x) \), because: \( \frac{d \ln(x)}{dx} = \frac{1}{x} \) see "Differentiation"!

\[
\Rightarrow \int_{x_1}^{x_2} x^{-1} \, dx = \int_{\ln(x_1)}^{\ln(x_2)} \ln(x) \, dx = [\ln(x)]_{x_1}^{x_2} = \ln(x_2) - \ln(x_1) = \ln \frac{x_2}{x_1}
\]