01:750:123H Honors Analytical Physics I

Lecture 1
Course Instructor

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Room & Time:
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Web page:
http://www.physics.rutgers.edu/ugrad/123H/
Course Overview

Classical mechanics: the science of motion

Motion in every day life
Planetary and satellite motion
(cosmic scale)
Mollecular and subatomic motion
(microscopic scale)
Mathematical model for motion

Isaac Newton 1689, *Principia Mathematica*
Basic motion in 1, 2 and 3 dimensions
What causes motion: **force**
How hard is it to stop a moving object?
How hard is it to move a stationary object?
Quanta of motion: momentum and energy
Circular motion. Gravity.
Oscillations.
Mathematical Background

Trigonometry.

Vector calculus.
Derivative: \[ \frac{df(x)}{dx} \]

Integral: \[ \int f(x)dx \]

Parallel math course: 01:640:CALC1.
Required Textbook

ISBN 9781118230640 (or the 9th edition.)
# Grade Evaluation

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
<th>Date</th>
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<tbody>
<tr>
<td>Homework</td>
<td>15%</td>
<td>12 assignments</td>
</tr>
<tr>
<td>Exam 1</td>
<td>15%</td>
<td>TBA</td>
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<tr>
<td>Exam 2</td>
<td>15%</td>
<td>TBA</td>
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<tr>
<td>Final</td>
<td>30%</td>
<td>TBA</td>
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<tr>
<td>Quiz</td>
<td>10%</td>
<td>~ weekly</td>
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<tr>
<td>Minilabs (group work)</td>
<td>10%</td>
<td>~ weekly</td>
</tr>
<tr>
<td>Attendance</td>
<td>5%</td>
<td>iClicker answers</td>
</tr>
</tbody>
</table>

**Final letter grade:** based on grade distribution.
Homework Assignments

• 12 assignments due at 1 or 2 week intervals
• 1st assignment due on Sept 18th 2019, 11:59pm.
• Internet based – Webassign: http://webassign.net/
• No late assignments accepted
• Lowest 2 homework assignments will be dropped.
Webassign:

- Access to Webassign is only through the link provided in your Sakai account.
- Need to purchase access code from RU bookstore or Webassign website
Exams

- All exams multiple choice

- Exams 1 and 2: 80 minutes, 15 problems

- The Final: 3 hour exam in the exam period.

  - Closed book, but you may bring one 8.5” x 11” sheet of paper (both sides) with formulas and notes to consult during the exam. You may also use a scientific calculator.

  - Practice problems and sample tests posted on course webpage
• ~ 4-5 questions/lecture

• answer 75% to get full credit for attendance
Register Your Clicker

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First Name:

Last Name:

Student ID:

Remote ID:

The ID assigned by your school. Check your syllabus or ask your instructor if you are unsure what to enter.

Image Code:

The verification code shown in the image above.

Register  Reset Form

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Note:

• short written quiz at the end of most recitations; 10-12 quizzes in total

• minilabs = physics concepts through experiments; group work

• lowest 2 quizzes and minilabs will be dropped

• no workshops the first week; will start the second week, Sept 9-13.
1. Measurement

All physical quantities are measured in terms of specific units.

- length: miles, yards, feet ...
- time: hours, minutes, seconds ...
- temperature: degrees

Standard units should be invariable: independent of

- physical characteristics of a particular observer
- geographic location, weather, seasons, ...
International System of Units (SI or metric system)

- 7 Base units:

<table>
<thead>
<tr>
<th>Base quantity</th>
<th>Name</th>
<th>Symbol</th>
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</thead>
<tbody>
<tr>
<td>length</td>
<td>meter</td>
<td>m</td>
</tr>
<tr>
<td>mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>time</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>electric current</td>
<td>ampere</td>
<td>A</td>
</tr>
<tr>
<td>thermodynamic temperature</td>
<td>kelvin</td>
<td>K</td>
</tr>
<tr>
<td>amount of substance</td>
<td>mole</td>
<td>mol</td>
</tr>
<tr>
<td>luminous intensity</td>
<td>candela</td>
<td>cd</td>
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The first 3 relevant for classical mechanics.
- **Second:**
  
  The time taken by 9,192,631,770 oscillations of
  the light emitted by a cesium-133 atom.

- **Meter:**
  
  The length of the path traveled by light in vacuum
  in a time interval of $\frac{1}{299,792,458}$ seconds.

- **Kilogram:**
  
  The mass of a platinum-irridium cylinder 0.039 m
  in height and diameter.
### Prefixes for SI Units

<table>
<thead>
<tr>
<th>Factor</th>
<th>Prefix$^a$</th>
<th>Symbol</th>
<th>Factor</th>
<th>Prefix$^a$</th>
<th>Symbol</th>
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<tbody>
<tr>
<td>$10^{24}$</td>
<td>yotta-</td>
<td>Y</td>
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<td>$10^{-24}$</td>
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1 cm = $10^{-2}$ m = 0.01 m  
1 km = $10^3$ m = 1000 m.
Changing units

\[ 1 \text{ ft} = 0.3048 \text{ m} \quad 1 \text{ lb} = 0.4536 \text{ kg} \]

\[ 1 \text{ m} = 3.281 \text{ ft} \quad 1 \text{ kg} = 2.205 \text{ lb} \]

Examples:

\[ 2.6 \text{ kg} = 2.6 \times 2.205 \text{ lb} = 5.733 \text{ lb} \]

\[ 0.7 \text{ cm} = 0.7 \times 10^{-2} \text{ m} = 0.7 \times 10^{-2} \times 3.281 \text{ ft} = 2.2967 \times 10^{-2} \text{ ft} \]
Derived units

• Area

\[ a = 2 \text{ m}, \quad b = 3 \text{ m} \]
\[ \text{Area} = 2\text{m} \times 3\text{m} = 6 \text{ m}^2 \]

\textbf{Square meter: area of a 1m} \times \text{1m square.}

\[ 1\text{m} \times 1\text{m} = 1 \text{ m}^2 \]
- **Volume**

\[ a = 2 \text{ m} \]

Volume = \(2\text{m} \times 2\text{m} \times 2\text{m} = 8 \text{ m}^3\)

**Cubic meter:** volume of a \(1\text{m} \times 1\text{m} \times 1\text{m}\) cube.

\[ 1\text{m} \times 1\text{m} \times 1\text{m} = 1 \text{ m}^3 \]
• Density

\[ \rho = \frac{\text{Mass}}{\text{Volume}} \]

Density unit = \( \frac{1 \, \text{kg}}{1 \, \text{m}^3} = 1 \, \frac{\text{kg}}{\text{m}^3} \)

= 1 kilogram per cubic meter

**Note:** scientific notation

5000000 = 5 \times 10^6 = 5E6

0.00007 = 7 \times 10^{-5} = 7E-5
2. Motion along a straight line

Goals:

- To introduce position and displacement in one dimension.
- To define and differentiate average and instantaneous linear velocity.
- To define and differentiate average and instantaneous linear acceleration.
- To explore some applications of one dimensional motion with constant acceleration.
- To examine freely falling bodies.
One dimensional motion.

- Motion is along a straight line only.
- Will study the characteristics of motion i.e. kinematics, not its cause (dynamics.)
- Physical objects will be assumed pointlike.

Good model

Elementary particles.

Spaceship between Earth and Mars.
Car in parking lot.

Spaceship in asteroid cloud.

**Note:** scale is very important in physics!
• Fix origin $\Rightarrow$ position determined by one number $x$
• Positive direction $x \uparrow$
• Negative direction $x \downarrow$
• **Displacement**: change from position $x_1$ to $x_2$

$$\Delta x = x_2 - x_1$$

• **Displacement** is a **vector** quantity

$\left\{\begin{array}{ll}
\text{magnitude} \\
\text{direction}
\end{array}\right.$

$x_1 = 3\text{m}, \quad x_2 = 8\text{m} \quad \Rightarrow \quad \Delta x = 5\text{m} > 0 \quad \text{Positive direction}$

$x_1 = 8\text{m}, \quad x_2 = 3\text{m} \quad \Rightarrow \quad \Delta x = -5\text{m} < 0 \quad \text{Negative direction}$
\[ \Delta x = (\text{Sign})|\Delta x|, \quad |\Delta x| > 0. \]

|\(\Delta x|\) = **Magnitude**: distance covered from initial to final position.

**Sign**: direction of motion from initial to final position.

+ \(\leftrightarrow\) positive direction.

− \(\leftrightarrow\) negative direction.

**Note**: displacement depends only on the initial and final position.
i-Clicker:

Suppose a particle moves from $x = 2\text{m}$ out to $x = 5\text{m}$ and back to $x = 2\text{m}$. Then the displacement is:

(A) $\Delta x = 3\text{m}$

(B) $\Delta x = -3\text{m}$

(C) $\Delta x = 0\text{m}$

(D) $\Delta x = 5\text{m}$

(E) $\Delta x = 2\text{m}$
Answer

Suppose a particle moves from \( x = 2m \) out to \( x = 5m \) and back to \( x = 2m \). Then the displacement is:

(A) \( \Delta x = 3m \)

(B) \( \Delta x = -3m \)

(C) \( \Delta x = 0m \)

(D) \( \Delta x = 5m \)

(E) \( \Delta x = 2m \)

Initial position:
\[ x_1 = 2m \]

Final position:
\[ x_2 = 2m \]
\[ \Delta x = 2m - 2m = 0m \]
Average velocity and average speed

- One dimensional motion ↔ graph of the position $x$ as function of time $t$
• **Average velocity:** rate of change of position

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$$

$$x_1 = x(t_1) \text{ position at time } t_1$$

$$x_2 = x(t_2) \text{ position at time } t_2 > t_1$$

$v_{avg}$ vector quantity: same sign as $\Delta x$ since $t_2 - t_1 > 0$

Units for $v_{avg}$: meter/second = m/s.
Geometric interpretation:

This is a graph of position $x$ versus time $t$. To find average velocity, first draw a straight line, start to end, and then find the slope of the line.

\[ v_{\text{avg}} = \text{slope of straight line connecting the points } (t_1, x_1), (t_2, x_2). \] Above \[ v_{\text{avg}} = \frac{6}{3} \text{ m/s} = 2 \text{ m/s}. \]
• **Average speed**

\[
s_{\text{avg}} = \frac{\text{total distance travelled in time interval } \Delta t}{\Delta t}
\]

\(s_{\text{avg}}\) scalar quantity; no sign, no direction.

**Units** for \(s_{\text{avg}}\): meter/second = m/s.
i-Clicker

A particle moves from $x = 0\,\text{m}$ to $x = 3\,\text{m}$ and then from $x = 3\,\text{m}$ to $x = 1\,\text{m}$ as shown in the graph below. Then $v_{\text{avg}}$ is:

(A) $v_{\text{avg}} = 1\,\text{m/s}$
(B) $v_{\text{avg}} = 0.75\,\text{m/s}$
(C) $v_{\text{avg}} = 1.25\,\text{m/s}$
(D) $v_{\text{avg}} = 0.25\,\text{m/s}$
(E) none of the above
Answer

A particle moves from \( x = 0 \text{m} \) to \( x = 3 \text{m} \) and then from \( x = 3 \text{m} \) to \( x = 1 \text{m} \) as shown in the graph below. Then \( v_{\text{avg}} \) is:

\[ \Delta x = 1 \text{m} - 0 \text{m} = 1 \text{m}, \quad \Delta t = 4 \text{s}, \quad v_{\text{avg}} = \frac{1}{4} \text{m/s} = 0.25 \text{m/s} \]
i-Clicker

For the same graph $s_{avg}$ is:

(A) $s_{avg} = 1\text{ m/s}$
(B) $s_{avg} = 1.25\text{ m/s}$
(C) $s_{avg} = 0.25\text{ m/s}$
(D) $s_{avg} = 0.75\text{ m/s}$
(E) none of the above.
Answer

For the same graph $s_{avg}$ is:

(A) $s_{avg} = 1\text{m/s}$
(B) $s_{avg} = 1.25\text{m/s}$
(C) $s_{avg} = 0.25\text{m/s}$
(D) $s_{avg} = 0.75\text{m/s}$
(E) none of the above.

Total distance $3\text{m} + 2\text{m} = 5\text{m}$, $\Delta t = 4\text{s}$,
$s_{avg} = \frac{5}{4}\text{m/s} = 1.25\text{m/s}$. 
Instantaneous velocity and speed

- **Instantaneous velocity**: velocity of a particle at a given moment in time.

\[ v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt} \]

\[ v = \text{limit of } v_{\text{avg}} \text{ over smaller and smaller time intervals } \Delta t \text{ centered at a current point } (x, t) \]
Geometric interpretation

\[ v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \text{slope of the tangent line to motion graph at current point} = \frac{dx}{dt} \text{ (derivative)} \]
Note: $v$ is a vector quantity \( \left\{ \begin{array}{c} \text{direction} \\ \text{magnitude} \end{array} \right. \)

- **Instantaneous speed**: magnitude of $v$

\[
s = |v| = \left| \frac{dx}{dt} \right|
\]

Units for $v, s$: $m/s$. 

Which of the following velocity graphs represents a car initially moving forward and then reversing direction?

(A)
(B)
(C)
(D)
(E) none of the above
Answer

Which of the following velocity graphs represents a car initially moving forward and then reversing direction?

(A)

(B)

(C)

(D)

(E) none of the above

The velocity must be $v = 0$ at some instant in time.
Acceleration

- **Acceleration**: the rate of change of velocity.

- **Average acceleration**

\[
a_{\text{avg}} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}
\]

\[
v_1 = v(t_1) \text{ instantaneous velocity at time } t_1
\]

\[
v_2 = v(t_2) \text{ instantaneous velocity at time } t_2 > t_1
\]

\(a_{\text{avg}}\) vector quantity: same sign as \(\Delta v\) since

\[t_2 - t_1 > 0\]
• **Instantaneous acceleration**

\[ a = \lim_{{\Delta t \to 0}} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} \]

**Note:** \( a \) is a vector quantity \( \{ \) direction, magnitude \( \} \)

**Units for** \( a_{\text{avg}}, a \) :

\( (\text{meter/second})/\text{second} = \text{m/s}^2 \).
**Geometric interpretation:** velocity graph

\[ a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} \]

\[ = \text{slope of the tangent line to motion graph at current point} \]

\[ = \frac{dv}{dt} \]

Alternative formula:

\[ a = \frac{d^2x}{dt^2} \quad \text{(second derivative)} \]