Dynamics!
Definitions
Newton's Laws
Applying
Newton's Laws
This course so far

Discussion - 4

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Fun Physics Question for the Day

Dynamics!
- Definitions
- Newton’s Laws

Applying Newton’s Laws

This course so far
Why is a solid solid?

- Nucleus is very tiny $10^{-15} \, m$, compared to the distance of orbit of the electron $5 \times 10^{-11} \, m$.
- Like a grape-seed in a football stadium
- What’s in-between? “Empty” space!
- Then why is matter solid?
Outline

1. Fun Physics Question for the Day

2. Dynamics!
   - Definitions
   - Newton’s Laws

3. Applying Newton’s Laws

4. This course so far
Outline

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Why do objects move?

- **Dynamics** answers the question *why* do objects move?
- **Force** is a push or a pull on some object.

**Forces**

- **Contact Forces** are due to physical contact of objects.
- **Field Forces** are due to interactions between objects. They act over a distance.
Resistance to Change

- **Inertia** refers to the tendency of objects to not change their state of motion.
  - Objects that are at rest continue to remain so.
  - Objects moving in straight lines continue to do so.
- **Mass** is a measure of inertia.
- Aside: Massless objects moving at the speed of light also have inertia.
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These are not laws, but a theory. Are violated in certain limits.
Newton’s First Law

Statement: Objects tend to remain at rest or continue moving along straight lines, unless acted upon by a force.

When there is no force...

- Objects that are moving continue to move along straight lines.
- Objects that are at rest continue to remain at rest.

Also called the law of inertia. Search the web for videos of the “tablecloth trick”. Here’s one.
Newton’s Second Law

The most useful, since it tells us **how to calculate acceleration**.

Recall: In kinematics, we were given the acceleration. Second law tells us how to calculate it given the forces

\[ \vec{F} = m \vec{a} \]  

(1)

**Newton’s Second Law**

In words: the acceleration...

- in magnitude, is proportional to the force
- is in the same direction as the force
- is lower if the mass is higher (more inertia)
Newton’s Second Law

Hey, but acceleration due to gravity doesn’t depend on the mass!

That’s because the force itself is proportional to the mass, and therefore it cancels.

Newton’s Universal Law of Gravitation:

Every object with mass attracts every other object with a force given by:

$$\vec{F}_{12} = -G \frac{m_1 m_2}{|\vec{r}_2 - \vec{r}_1|^2} \hat{r}_{12}$$  \hspace{1cm} (2)
Newton’s Second Law

The second law is a vector equation. So we can resolve it into components:

\[ F_x = ma_x \]  \hspace{1cm} (3)

\[ F_y = ma_y \]  \hspace{1cm} (4)

**Units of Force**

Force is measured in newtons (N).

\[ 1 \text{ N} = 1 \text{ kg} \text{ m} \text{ s}^{-2} \]  \hspace{1cm} (5)
Newton’s Third Law

Every action has an equal and opposite reaction.
⇒ If you push the wall, the wall pushes you.

\[ \vec{F}_{12} = -\vec{F}_{21} \]
The four fundamental interactions

- **Electromagnetism** – chemical bonding, friction, springiness (upon pulling things)
- **Gravity** – solar system, keeps stars together in galaxies, large-scale structure of the universe
- **Strong** – keeps the nucleus together
- **Weak** – responsible for radioactivity ($\beta$-decay etc.)
Why is a solid solid?

Origin of contact forces is Quantum Mechanical.

“Pauli’s Exclusion Principle”

Figure: Licensed under CC-BY-SA 3.0. Original source on Wikipedia
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Taming the Second Law
Problem Solving Strategy:

- Start by drawing a figure, identify the forces
- Draw a free body diagram, mark the forces – magnitude and direction
- Choose a reference frame
- Resolve all forces into x and y components
- Use $\vec{F} = m\vec{a}$ to find the acceleration
- Use kinematics to answer any further questions about the motion
Problems!

The key to applying Newton’s second law correctly to quantitative problems is practice and the attitude of not giving up till the problem is conquered.
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This course so far...

This section of slides summarizes important aspects of the course so far.

Ensure that you know all of these before the examination. Please bring some of your troubles for discussion during Wednesday’s session.

Note that this is not an exhaustive list. Also, these slides may have mistakes. Please ensure to cross-check with the textbook / your lecture notes.
Chapter 1 – Introduction

- Units (of length, mass and time)
  - Names of the units
  - Conversion between units (retain significant figures!!)

- Dimensions
  - Rules for dimensional consistency of addition / subtraction
  - Rules for dimensions under multiplication / division
  - Finding the dimensions of a given quantity
  - Checking equations for dimensional consistency
  - Deriving an equation from dimensional analysis
Chapter 1 – Introduction

- Significant Figures
  - Rules for addition
  - Rules for multiplication
- Order of Magnitude estimation
  - Approximate to the nearest 10.
  - Practice!
Chapter 1 – Introduction

- Trigonometry
  - Definitions of sin, cos, tan, ...
  - Useful relations
  - arcsin, arccos, arctan

- Coordinate Geometry
  - Identifying slope and intercept of a given equation / plot of a straight line
  - Writing the equation of a straight line given a plot.
  - Conversion between Cartesian and Polar coordinates.
Chapter 2 – Motion in 1 dimension

- Definitions of particle, distance, displacement, instantaneous velocity, average velocity, speed, average speed, acceleration
- Reading an x-t plot to find these quantities
- Kinematic equations:
  \[ x = x_0 + v_0 t + \frac{1}{2} at^2 \]  \hspace{1cm} (7)
  \[ v = v_0 + at \]  \hspace{1cm} (8)
- Free-fall and acceleration due to gravity
  - Calculating height reached, given initial velocity or vice versa
  - Calculating time of flight
Chapter 3 – Motion in 2 dimensions

- **Vectors**
  - Resolving vector given as magnitude, direction into x and y components.
  - Finding the magnitude and direction given x and y components.
  - Vector operations: addition, subtraction, multiplication by a scalar, dot product.
- **Kinematics in 2 dimensions:**

\[
\begin{align*}
  x &= x_0 + v_{x0}t + \frac{1}{2}a_xt^2 \\
  y &= y_0 + v_{y0}t + \frac{1}{2}a_yt^2 \\
  v_x &= v_{x0} + a_xt \\
  v_y &= v_{y0} + a_yt
\end{align*}
\]
Chapter 3 – Motion in 2 dimensions

- projectile motion
  - Calculating range, flight time, max. height
  - Calculating angle to throw at to hit something
  - Inverse problems
  - More complicated scenarios involving multiple objects moving

- Relative motion:
  Velocity of A w.r.t. C = Velocity of A w.r.t B + Velocity of B w.r.t. C.
Newton’s First Law

- Concept of inertia
- Mass
- Conceptual understanding of 1st law
Newton’s Second Law

\[ \vec{F} = m\vec{a}, \text{ or} \]  

\[ F_x = ma_x \quad (15) \]

\[ F_y = ma_y \quad (16) \]
Chapter 4 – Newton’s Laws

- Newton’s Third Law – concept
- Applying Newton’s Laws:
  - Handling various forces:
    - Contact forces from surfaces!
    - String tension
    - Handling situations on an inclined plane
  - Effect of acceleration on the apparent weight of an object
- Practice! And be strong-willed!