Physics 207, Lecture 4, Sept. 17

Agenda

- Chapter 3, Chapter 4 (forces)
  - ❖ Vector addition, subtraction and components
  - ❖ Inclined plane
  - ❖ Force
  - ❖ Mass
  - ❖ Newton's 1st and 2nd Laws
  - ❖ Free Body Diagrams

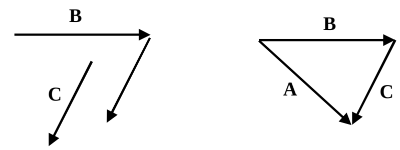
Assignment: Read Chapter 5

- MP Problem Set 2 due Wednesday (should have started)
- MP Problem Set 3, Chapters 4 and 5 (available soon)

Vector addition

- The sum of two vectors is another vector.

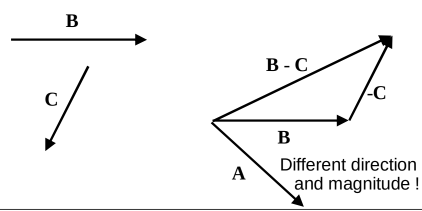
A = **B** + **C**



Vector subtraction

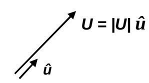
- Vector subtraction can be defined in terms of addition.

B - C = **B** + (-1)**C**



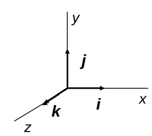
Unit Vectors

- A **Unit Vector** is a vector having length 1 and no units
- It is used to specify a direction.
- Unit vector ***u*** points in the direction of ***U***
  - ❖Often denoted with a "hat": ***u = û***



- Useful examples are the cartesian unit vectors [***i, j, k***]
  - ❖ Point in the direction of the *x*, *y* and *z* axes.

$R = r_x \mathbf{i} + r_y \mathbf{j} + r_z \mathbf{k}$



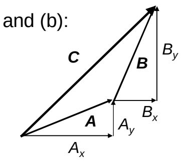
Vector addition using components:

- Consider ***C*** = ***A*** + ***B***.

(a) $C = (A_x \mathbf{i} + A_y \mathbf{j}) + (B_x \mathbf{i} + B_y \mathbf{j}) = (A_x + B_x)\mathbf{i} + (A_y + B_y)$

(b) $C = (C_x \mathbf{i} + C_y \mathbf{j})$

- Comparing components of (a) and (b):
  - ❖ $C_x = A_x + B_x$
  - ❖ $C_y = A_y + B_y$



Lecture 4, *Exercise 1*
Vector Addition

- Vector **A** = {0,2,1}
- Vector **B** = {3,0,2}
- Vector **C** = {1,-4,2}

What is the resultant vector, **D**, from adding **A**+**B**+**C**?

A) *{3,-4,2}* B) *{4,-2,5}* C) *{5,-2,4}*

Lecture 4, *Exercise 1*
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B. *{4,-2,5}*
C. *{5,-2,4}*
D. None of the above

Converting Coordinate Systems

- In ***polar*** coordinates the vector ***R*** = (r,θ)
- In Cartesian the vector ***R*** = (r_x,r_y) = (x,y)
- We can convert between the two as follows:

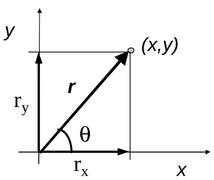
$r_x = x = r\cos\theta$

$r_y = y = r\sin\theta$

$R = x\,\hat{i} + y\,\hat{j}$

$r = \sqrt{x^2+y^2}$

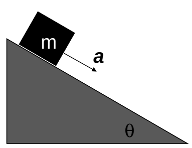
$\theta = \tan^{-1}(y/x)$



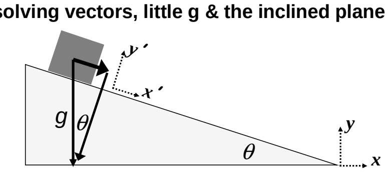
- In 3D cylindrical coordinates (*r*,θ,*z*), *r* is the same as the magnitude of the vector in the *x-y* plane [*sqrt*(x^2 +y^2)]

Exercise: Frictionless inclined plane

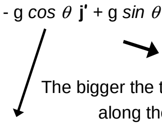
- A block of mass *m* slides down a frictionless ramp that makes angle θ with respect to horizontal. What is its acceleration *a* ?



Resolving vectors, little g & the inclined plane



- **g** (bold face, vector) can be resolved into its *x,y* **or** *x',y'* components
  - **g** = - g **j**
  - **g** = - g *cos θ* **j'** + g *sin θ* **i'**

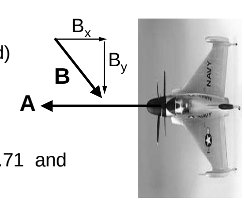


  - The bigger the tilt the faster the acceleration….. along the incline

Lecture 4, Example
Vector addition

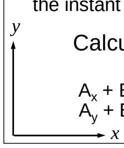
An experimental aircraft can fly at full throttle in still air at 200 m/s. The pilot has the nose of the plane pointed west (at full throttle) but, unknown to the pilot, the plane is actually flying through a strong wind blowing from the northwest at 140 m/s. Just then the engine fails and the plane starts to fall at 5 m/s^2.

What is the magnitude and directions of the resulting velocity (relative to the ground) the instant the engine fails?



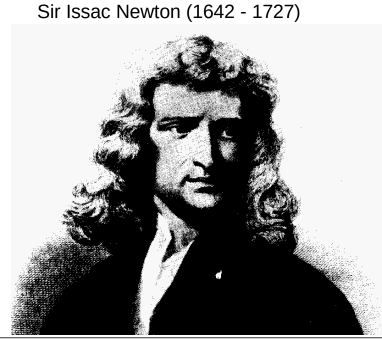
Calculate: **A** + **B**

$A_x + B_x = -200 + 140 \times 0.71$ and
$A_y + B_y = 0 - 140 \times 0.71$



And now, Chapter 4: Newton's Laws and Forces

Sir Issac Newton (1642 - 1727)



Dynamics

- Principia Mathematica published in 1687. This revolutionary work proposed three “laws” of motion:

Law 1: An object subject to no net external forces is at rest or moves with a constant velocity if viewed from an inertial reference frame.

Law 2: For any object, $\boldsymbol{F}_{NET} = \Sigma \boldsymbol{F} = m\boldsymbol{a}$

Important: Force is a vector and this is a vector sum

Law 3: Forces occur in pairs: $\boldsymbol{F}_{A,B} = -\boldsymbol{F}_{B,A}$

(Deferred until later)

So…What is a force and how do we know it is there?

Force

- We have a general notion of forces is from everyday life.
- In physics the definition must be precise.
  - ❖A force is *an action which causes a body to accelerate*.

(Newton’s Second Law)

Examples:

Contact Forces	Field Forces (Non-Contact)
(physical contact between objects)	(action at a distance)
Kicking a ball	Moon and Earth

- On a microscopic level, all forces are non-contact

Mass

- We have an idea of what mass is from everyday life.
- In physics:
  - ❖ Mass (in Phys 207) is *a quantity that specifies how much inertia an object has*

  (i.e. a scalar that relates force to acceleration)

  (Newton’s Second Law)
- Mass is an inherent property of an object.
- Mass and weight are different quantities; weight is usually the magnitude of a gravitational (non-contact) force.

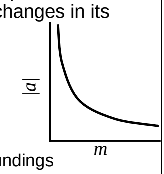
“Pound” (lb) is a definition of weight (i.e., a force), not a mass!

Inertia and Mass

- The tendency of an object to resist any attempt to change its velocity is called ***Inertia***
- ***Mass*** is that property of an object that specifies how much resistance an object exhibits to changes in its velocity (acceleration)

  If mass is constant then $\vec{a} \propto \vec{F}_{\text{net}}$

  If force constant $|\vec{a}| \propto \frac{1}{m}$ →



- Mass is an inherent property of an object
- Mass is independent of the object’s surroundings
- Mass is independent of the method used to measure it
- Mass is a scalar quantity
- The SI unit of mass is kg

Lecture 4, *Exercise 2*
Newton’s Laws and context

- An object is moving to the right, and experiencing a net force that is directed to the right. The magnitude of the force is decreasing with time.
- The speed of the object is

A. increasing
B. decreasing
C. constant in time
D. Not enough information to decide

Lecture 4, Sept. 17, Recap

Assignments:

- For Wednesday class: Read Chapter 5
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Newton's First Law and IRFs

An object subject to no external forces moves with a constant velocity if viewed from an *inertial reference frame (IRF)*.

If no net force acting on an object, there is no acceleration.

- The above statement can be used to define inertial reference frames.
  - ❖ An IRF is a reference frame that is not accelerating (or rotating) with respect to the "fixed stars".
  - ❖ If one IRF exists, infinitely many exist since they are related by any arbitrary constant velocity vector!
  - ❖ The surface of the Earth may be viewed as an IRF

Newton's Second Law

The acceleration of an object is directly proportional to the net force acting upon it. The constant of proportionality is the mass.

$$\sum \vec{F} = \vec{F}_{NET} = m\vec{a}$$

- This expression is vector expression: F_x, F_y, F_z
- Units
  The metric unit of force is kg m/s^2 = Newtons (N)
  The English unit of force is Pounds (lb)

Important notes

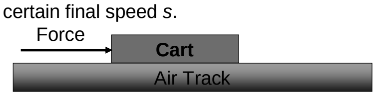
- Contact forces are conditional, they are not necessarily constant
- The SI units of force are Newtons with 1 N= 1 kg m/s^2

Now recall

- If net force is non-zero & constant then the change in the velocity is simply acceleration times time.
- If we double the time we double, keeping the force constant, then the change in velocity (assuming mass is constant)

Lecture 4, *Exercise 3*
Newton's Second Law

A constant force is exerted on a cart that is initially at rest on an air table. The force acts for a short period of time and gives the cart a certain final speed *s*.



In a second trial, we apply a force only **half** as large.

To reach the same final speed, how long must the same force be applied (recall acceleration is proportional to force if mass fixed)?

A. 4 x as long
B. 2 x as long
C. 1/2 as long
D. 1/4 as long

Lecture 4, *Exercise 3*
Newton's Second Law
Solution

F = ma
Since $F_2 = 1/2\ F_1 \Rightarrow a_2 = 1/2\ a_1$

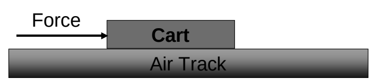
We know that under constant acceleration, $v = a\,\Delta t$

So,
$a_2\,\Delta t_2 = a_1\,\Delta t_1$ we want equal final velocities
$1/2\ a_1 / \Delta t_2 = a_1 / \Delta t_1$ $\quad \Delta t_2 = 2\,\Delta t_1$

(B) 2 x as long

Lecture 4, *Exercise 4*
Newton's Second Law

A force of 2 Newtons acts on a cart that is initially at rest on an air track with no air and pushed for 1 second. Because there is friction (no air), the cart stops immediately after I finish pushing.
It has traveled a distance, *D*.

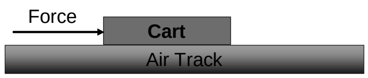


Next, the force of 2 Newtons acts again but is applied for 2 seconds.

The new distance the cart moves relative to *D* is:

A. 8 x as far
B. 4 x as far
C. 2 x as far
D. 1/4 x as far

Lecture 4, *Exercise 4*
Solution



We know that under constant acceleration,
$\Delta x = a(\Delta t)^2/2$ (when $v_0=0$)

Here $\Delta t_2 = 2\Delta t_1$, $F_2 = F_1 \Rightarrow a_2 = a_1$

$$\frac{\Delta x_2}{\Delta x_1} = \frac{\frac{1}{2} a \Delta t_2^2}{\frac{1}{2} a \Delta t_1^2} = \frac{(2\Delta t_1)^2}{\Delta t_1^2} = 4$$

(B) 4 x as long

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