Engineering Physics (FIC 102)

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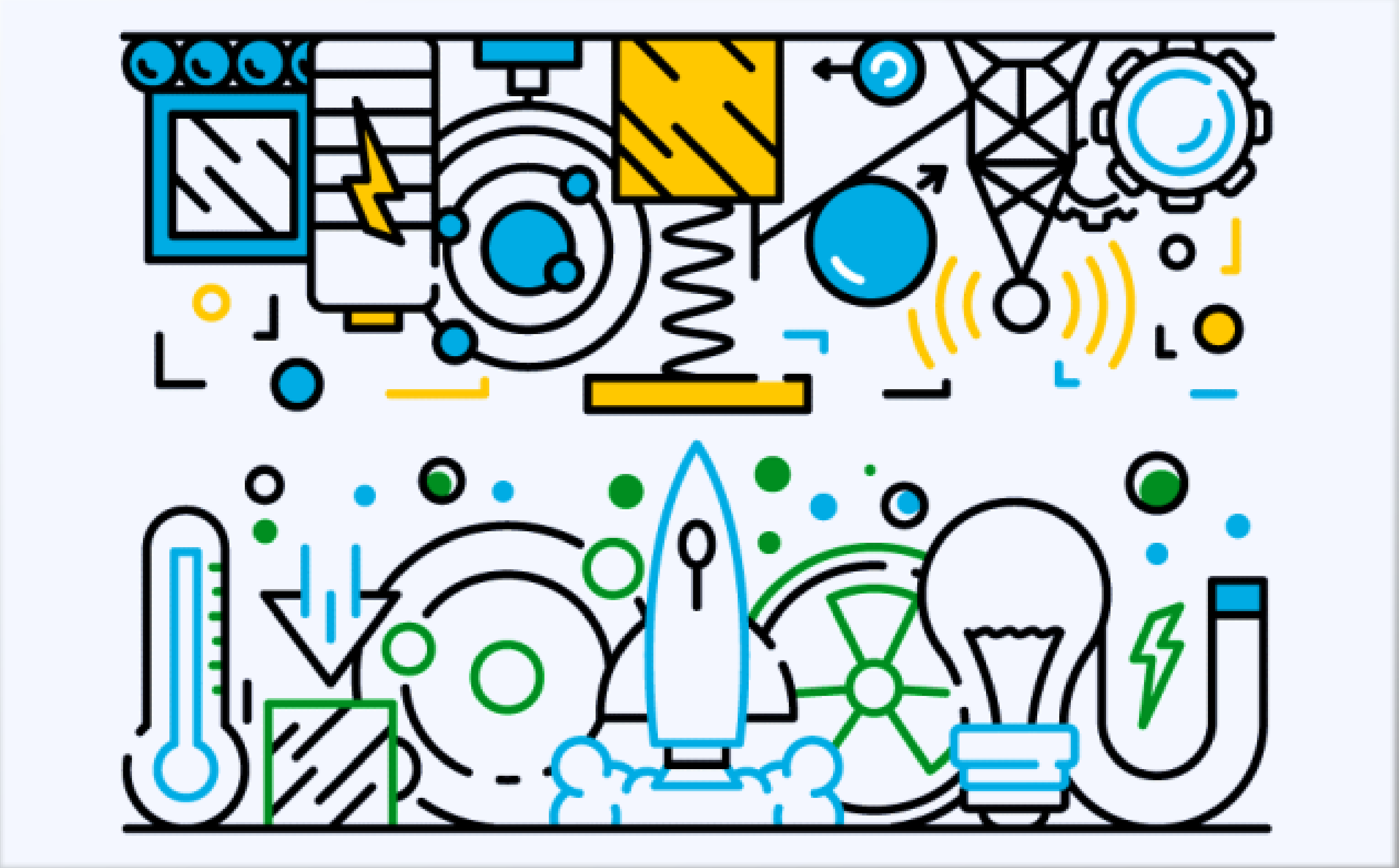


Course Objectives

- Objective 1: To understand the fundamental concepts of physics and their application in engineering.
- Objective 2: To develop problem-solving skills through physics-based problems.
- Objective 3: To enhance practical knowledge through laboratory experiments and real-world applications.
- Objective 4: To foster analytical and critical thinking skills.

Course Outcome (COs)

- Demonstrate understanding of core physics principles in mechanics, waves, modern physics, and electromagnetism
- Apply physics principles to analyse and solve engineering physics problems
- Demonstrate problem-solving skills using mathematical tools
- Evaluate experimental data to interpret and explain the underlying physics

CONTENT

MARK DISTRIBUTION

(A) Continuous Evaluation	Assessment tool	Conducting Marks	Converting Marks	Final Conversion
Theory + Practical	**Mid-term**	25	20	50
	CLA-I Class test(30%) , Poll/Quiz (15%), Assignments (15%), Lab performance (15%), Model exam (15%), Observation note (10%)	15	15	
	CLA-II Class test(30%) , Poll/Quiz (15%), Assignments (15%), Lab performance (15%), Model exam (15%), Observation note (10%)	15	15	
			Total	50

(B) End Semester	Assessment tool	Conducting Marks	Final Conversion
End semester theory exam	**Final exam**	100	30
End semester Practical exam	Exam performance (60%) Practical record (20%) Viva (20%)	100	20
		Total	50

Total Marks = (A) + (B) = 100

Syllabus

Unit 1	CLASSICAL PHYSICS
1.	Introduction
2.	Newton’s laws of mechanics, Free body force diagram
3.	Momentum and Impulse, Conservation of linear momentum
4.	Work-Kinetic Energy Theorem and related problems
5.	Conservation of mechanical energy: Worked out problems
6.	Elastic properties of solids, Stress-strain relationship, elastic constants, and their significance

Syllabus

Unit 2	OPTICS
7.	Concept of Electromagnetic waves & EMW Spectra
8.	Geometrical & Wave Optics: Laws of reflection and refraction
9.	Concept of Interference
10.	Phase Difference and Path Difference
11.	Double-Slit Interference
12.	Diffraction: types and single slit

Syllabus

Unit 3	MODERN PHYSICS
13.	Black Body Radiation; Wien's displacement law
14.	Discussion on failure of classical laws to explain Black Body Radiation, and concept of Planck's Hypothesis
15.	What is Light? Photon and Overview on Planck Constant
16.	Photoelectric effect – Concept and Experimental Setup
17.	Photoelectric effect – Intensity vs Current, Frequency vs Kinetic Energy, the drawback of Wave theory to explain Photoelectric effect
18.	Wave properties of particle: De Broglie wave

Syllabus

Unit 4	ELECTRO-MAGNETISM – I
19.	Focus on Maxwell's Equation I: Discuss lines of force and Electrostatic flux, Introduce Gauss's law (differential and integral form)
20.	Application of Gauss Law: ES field due to infinite wire and sheet.
21.	Electrostatic field due to conducting and insulating sphere.
22.	Concept of Electrostatic Potential and Potential Energy, corelation with electrostatic field.
23.	Capacitor and Capacitance
24.	Capacitance of a parallel plate capacitor

Syllabus

Unit 5	ELECTRO-MAGNETISM – II
25.	Introduce Biot-Savart Law as an alternative approach to calculate magnetic field.
26.	Calculate Magnetic field due to finite current element using Biot Savart Law.
27.	Focus on Maxwell's Equation IV: Discuss Ampere's circuital law.
28.	Calculate Magnetic field due to Infinite wire and Solenoid using Ampere's Law.
29.	Focus on Maxwell's Equation III: Lenz's Law and Faraday's law: Induced EMF and Current
30.	Describe Maxwell Equations as the foundation of electro-magnetism. Derive differential forms starting from Integral forms. Discuss Physical Significance.

List of Experiments:

- Hooke’s law and determine spring constant for a given spring
- Faraday law & Induced E.M.F: Measurement of the induced voltage and calculation of the magnetic flux induced by a falling magnet
- To study the magnetic field variation along the axis of Helmholtz coil., magnetic field along the axis of the circular coils, when the distance between them $a = R$, a=2R, a=R/2 (R=radius of the coils).
- Dielectric constant of air using dielectric constant kit.
- Michelson interferometer kit with diode laser
- He-Ne laser kit: Optical Interference and Diffraction
- Diffraction by Grating and Particle size measurement
- Verification of Stefan's Law

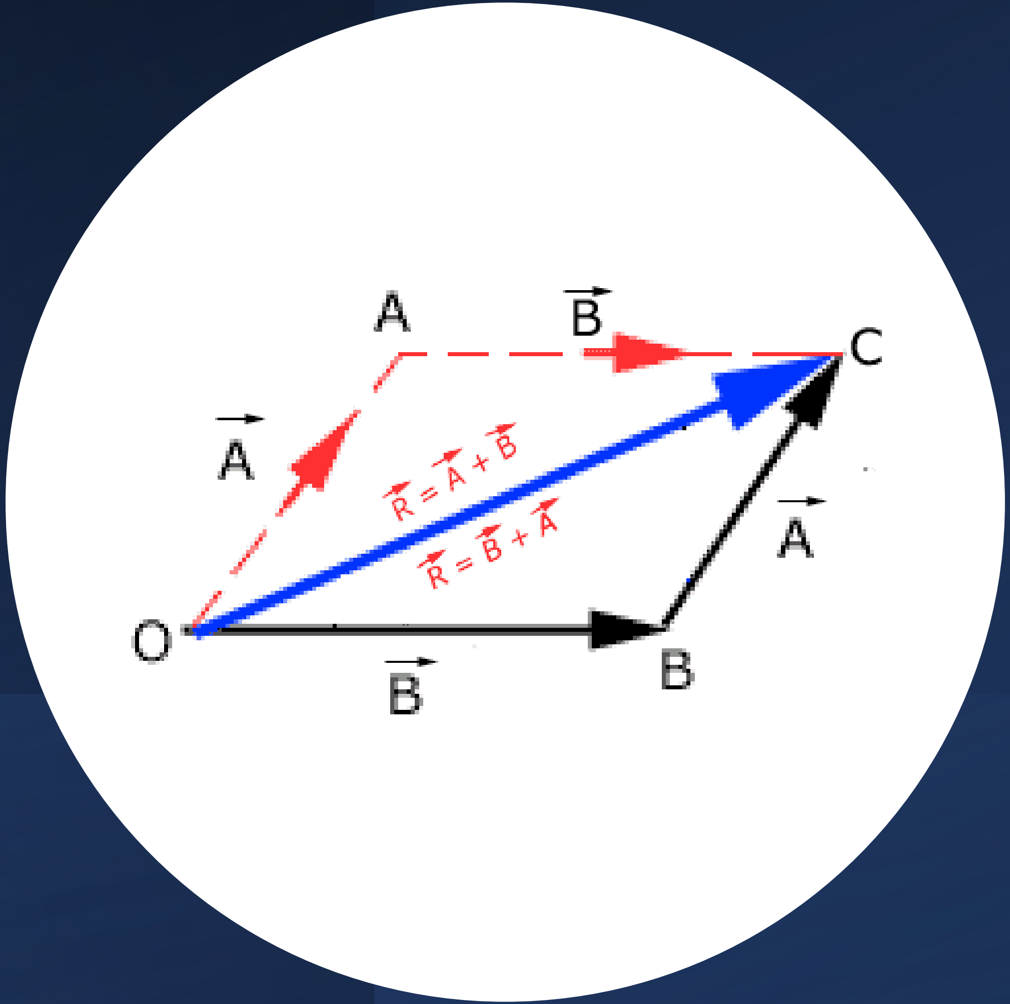
Recommended Resources

1. Physics for Scientist and Engineers - Raymond A. Serway, John W. Jewett, XIX Edition (2017), Publisher - Cengage India Private Limited
2. University Physics with Modern Physics with Mastering Physics - D Young, Roger A Freedman And Lewis Ford, XII Edition (2018), Publisher – PEARSON
3. Concept of Modern Physics - Arthur Beiser, Shobhit Mahajan, S Rai, 2017 Edition, Publisher - Tata McGraw Hill

Other Sources

4. Introduction to Electrodynamics – David J. Griffiths. 4th Edition (2012), Publisher - PHI Eastern Economy Editions
5. Introduction to Geometrical and Physical Optics, B. K. Mathur, 7 Edition, Gopal Printing

UNIT 1
LECTURE-01



Introduction to Vector and Coordinate systems

CONCEPT QUESTION

Find out the only vector from the following list

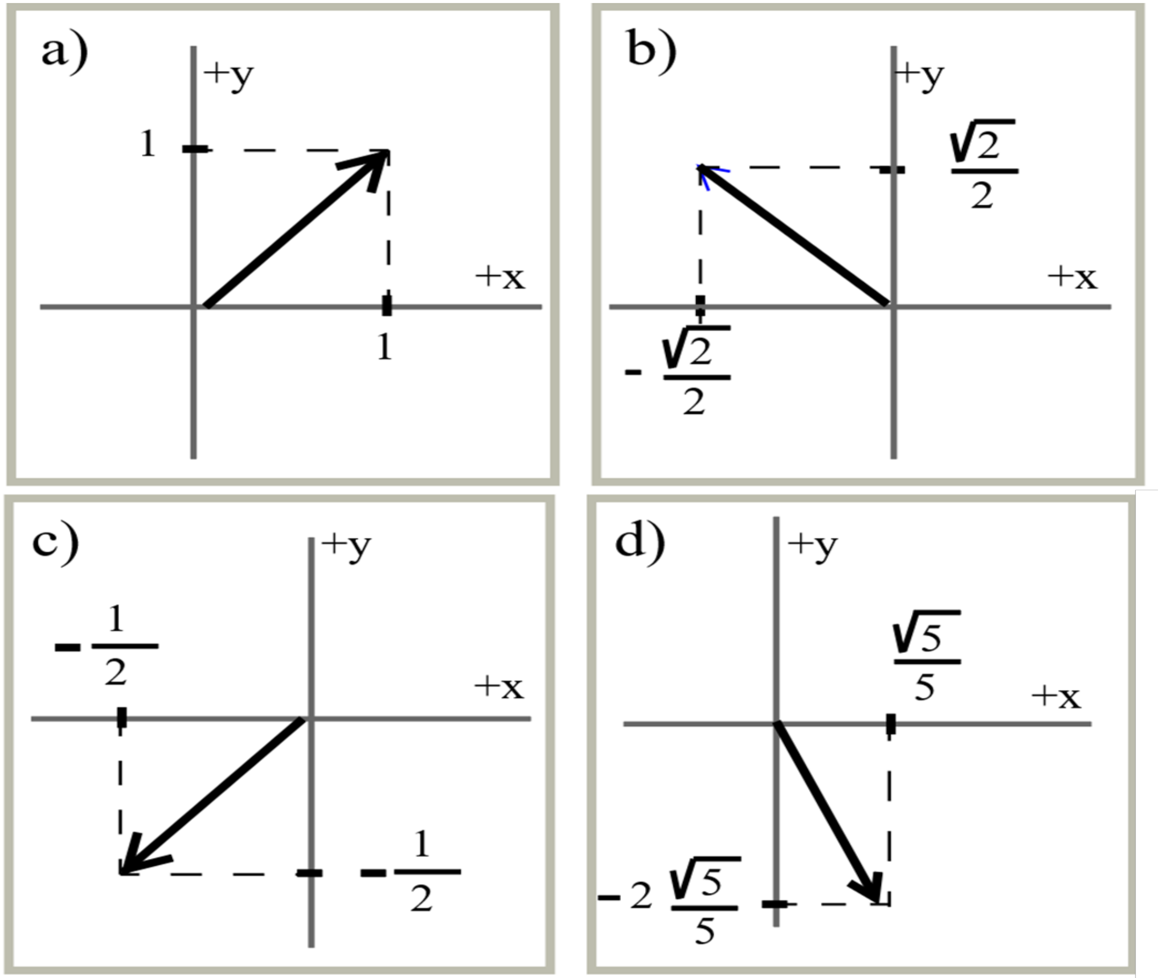
A. Temperature

B. Time

C. Velocity

D. Speed

CONCEPT QUESTION



Which one of these are unit vector(s)?

A. *Option (a)*

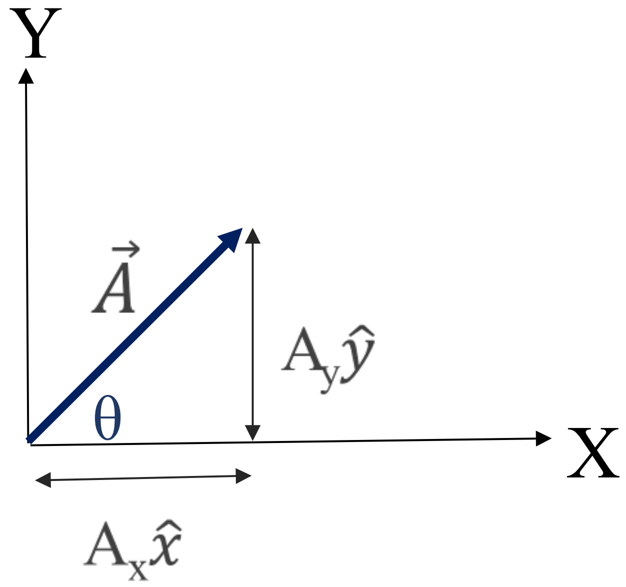
B. *Option (b)*

C. *Option (c)*

D. *Option (d)*

Vector Analysis

- The physical quantities that have magnitude, but no direction are called scalars. Examples: mass, charge, density, temperature.
- A vector quantity has both magnitude and direction, Examples: velocity, displacement, acceleration, force etc.
- A vector is represented by a symbol with an arrow above it, .
- For a vector



A_x and A_y are the components of the vector. along X and Y axes, respectively.

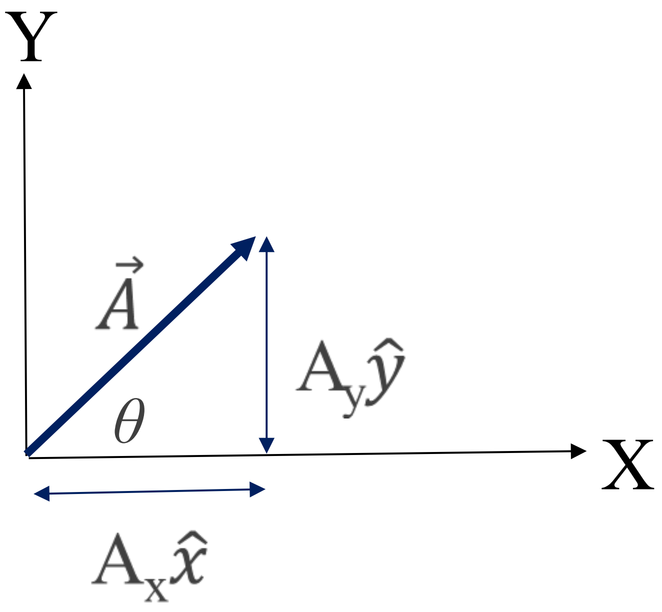
Vector Analysis

- The magnitude of the vector is = =
- From the diagram, $A_x = A\cos\theta$, $A_y = A\sin\theta$

  $\tan\theta =$ or

- In 3 dimensions, a vector is represented by

- Here A_x , A_y and A_z are the components of the vector.
- along X, Y and Z axes, respectively.



- **Unit vector** = =

Summary: Vector Operations

$$\vec{A}+\vec{B}=(A_x+B_x)\hat{x}+(A_y+B_y)\hat{y}+(A_z+B_z)\hat{z}$$

$$\vec{A}-\vec{B}=(A_x-B_x)\hat{x}+(A_y-B_y)\hat{y}+(A_z-B_z)\hat{z}$$

ADDITION

SUBTRACTION

VECTOR ANALYSIS

DOT PRODUCT

CROSS PRODUCT

$$\vec{A}\cdot\vec{B}=|\vec{A}||\vec{B}|\cos(\theta)$$

$$\theta=\cos^{-1}\frac{\vec{A}\cdot\vec{B}}{|\vec{A}||\vec{B}|}$$

if and are perpendicular

$$\cdot\vec{B}=(A_xB_x)+(A_yB_y)+(A_zB_z)$$

$$\vec{A}\times\vec{B}=|\vec{A}||\vec{B}|\sin(\theta)\hat{n}$$

$$\vec{A}\times\vec{B}=\hat{x}(AyBz-AzB_y)-\hat{y}(AxBz-AzB_x)+\hat{z}(AxBy-A$$

if and are parallel,

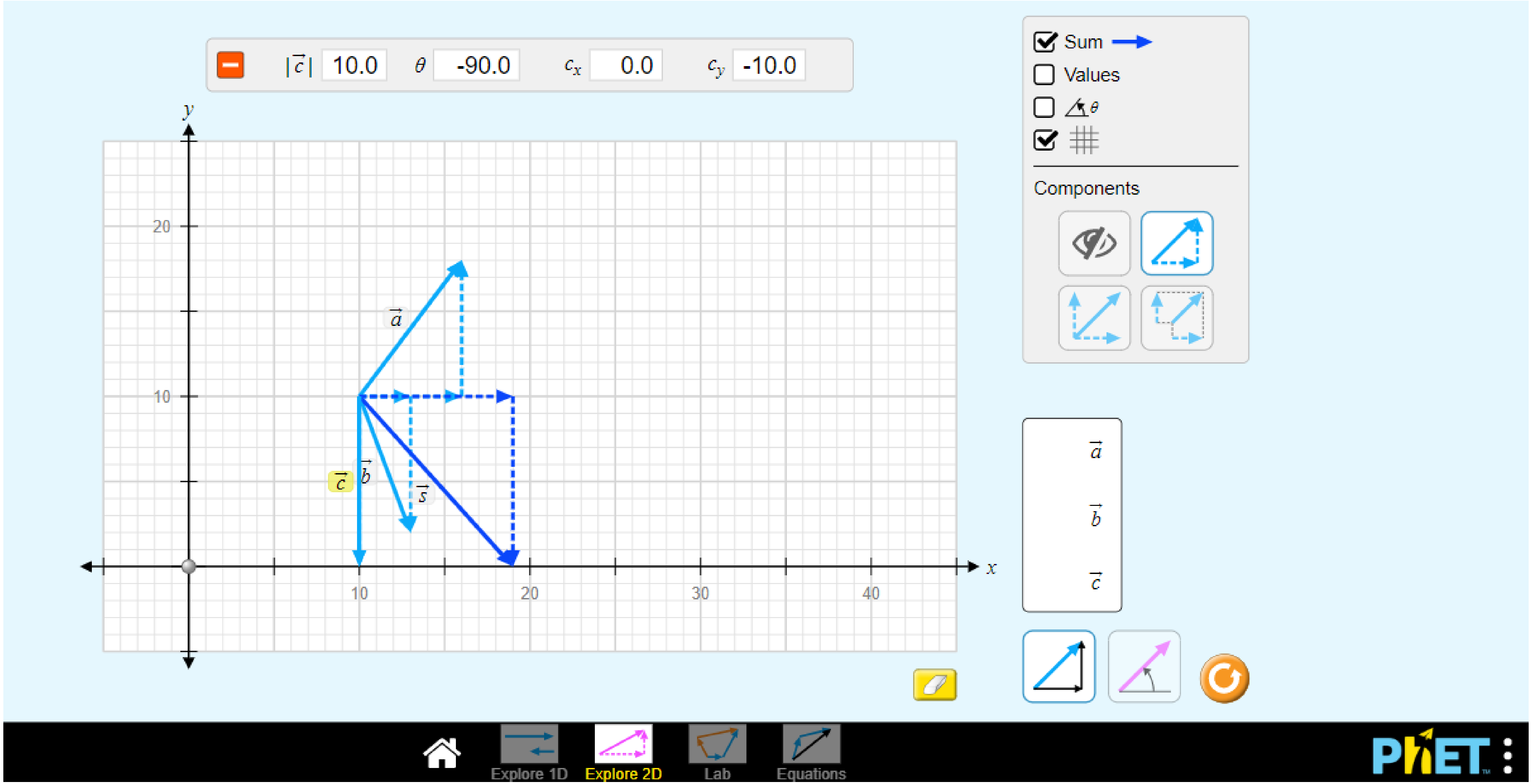
Vector Algebra

, ,

,

- Let's take
-
- *The unit normal vector perpendicular to the plane containing* and is

INTERACTIVE PRESENTATION



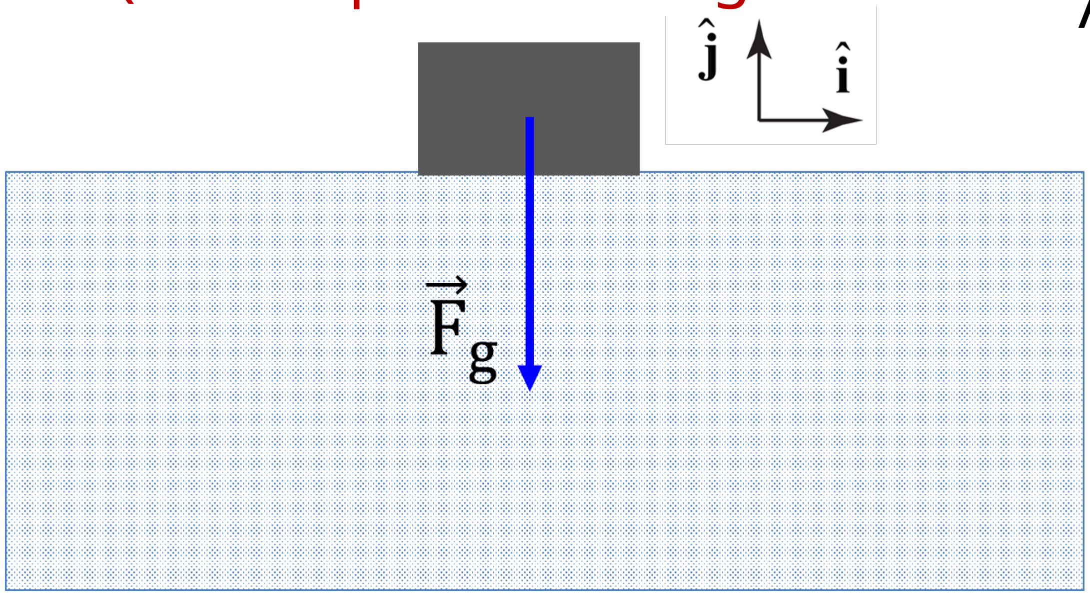
https://phet.colorado.edu/sims/html/vector-addition/latest/vector-addition_en.html

Choosing Coordinate system

Magnitude = F_q

X-component = 0

(as component along



Y-component = $-F_g$

(as component along

$$\vec{F} = \hat{i}(0) + \hat{j}(-F_g)$$

Used to describe the position of a point in space

A coordinate system consists of:

1. An origin at a particular point in space
2. A set of coordinate axes with scales and labels
3. Choice of positive direction for each axis: unit vectors
4. Choice of type: Cartesian or Polar or Spherical or cylindrical

Example: Cartesian One-Dimensional Coordinate System

POLL QUESTION

Given two vectors $A = 2\hat{i} - 3\hat{j} + 7\hat{k}$ and $B = 5\hat{i} + \hat{j} + 2\hat{k}$

$If\ \vec{C} = -3\hat{i} - 4\hat{j} + 5\hat{k}, define\ the\ vector\ operation$

A.

B.

C.

POLL QUESTION

Find out value of *X* if vector A & B are orthogonal

A. X=0

B. X=-1

C. X=-2

D. X=-3

$$\vec{A}=2\hat{i}-3\hat{j}+7\hat{k} \wedge \vec{B}=5\hat{i}+\hat{j}+(X)\hat{k}$$

For two vectors to be orthogonal, = 0

Practice problems

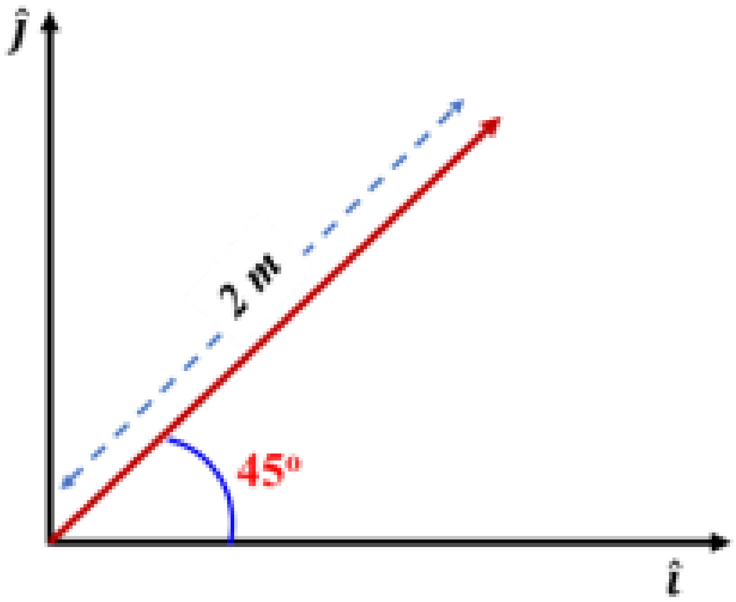
The unit vector along the direction shown in the figure is

(a) $2\hat{\imath} + 2\hat{\jmath}$

(b) $\frac{1}{\sqrt{2}}\hat{\imath} + \frac{1}{\sqrt{2}}\hat{\jmath}$

(c) $\hat{\imath} + \hat{\jmath}$

(d) $\sqrt{2}\hat{\imath} + \sqrt{2}\hat{\jmath}$



Find a unit vector perpendicular to $\vec{\mathbf{A}} = \hat{\mathbf{i}} + \hat{\mathbf{j}} - \hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = -2\hat{\mathbf{i}} - \hat{\mathbf{j}} + 3\hat{\mathbf{k}}$.

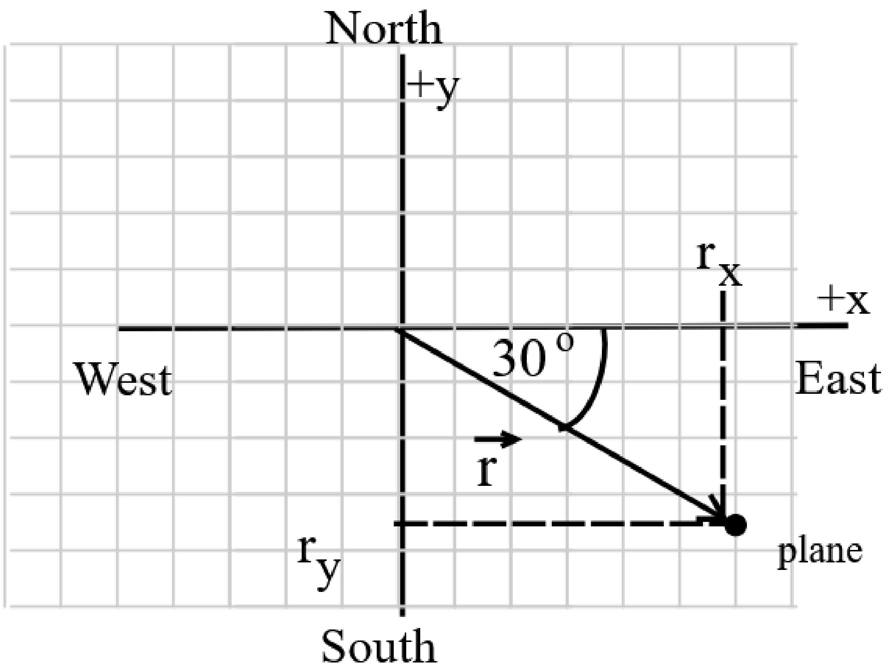
Solution:

Find Components given the Magnitude and Direction

At a given instant of time a plane is 100 km from the airport in a direction 30° south of east from the airport. If the $+x$ axis is pointing east and the $+y$ axis points north, then the plane's position vector at that instant is $\vec{\mathbf{r}} = x\hat{\mathbf{i}} + y\hat{\mathbf{j}}$, where

$x =$ [ ] km

$y =$ [ ] km



In this example, we know the magnitude and the direction of the vector and we need to find its components.

If $r = |\vec{\mathbf{r}}| = 100\,\mathrm{km}$ then the x and y components of $\vec{\mathbf{r}}$ are

$$x = r\cos(30^{\circ}) = 100\cos(30^{\circ}) = 100 \times 8.66 = 86.6\,\mathrm{km}$$
$$y = -r\sin(30^{\circ}) = -100\sin(30^{\circ}) = -100 \times 0.5 = -50\,\mathrm{km}\,.$$

LECTURE-02

Newton’s Law
Free Body Force Diagram

CONCEPT QUESTION

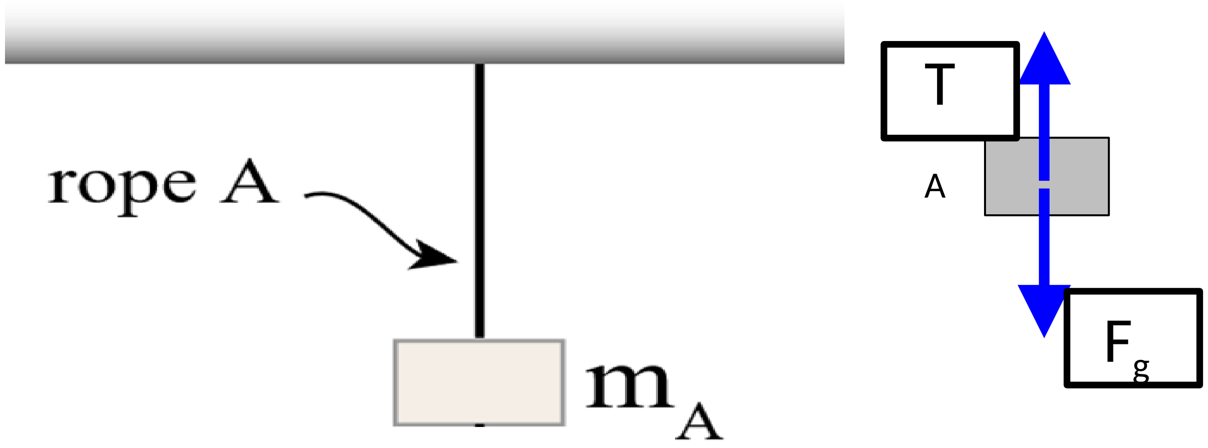
Mass m_A is hanging from a rope and resting without any motion or acceleration – equilibrium force pair T_A and F_g represent

A. Newton's First Law

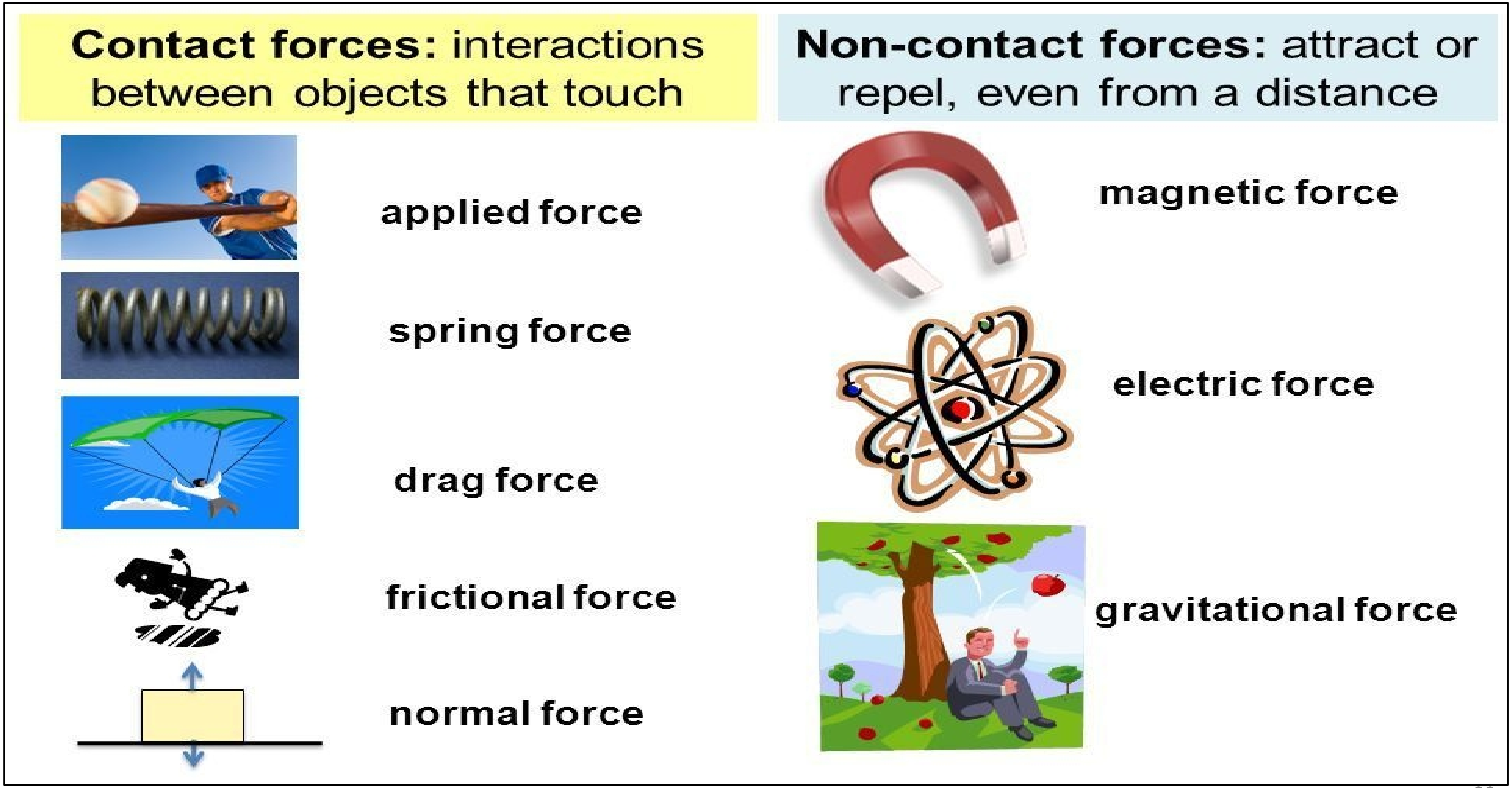
B. Newton's Second Law

C. Newton's Third Law

D. None of the above



Contact & Non-contact Forces



‘Newton’s Laws of Motion’

Newton’s 1st law of motion

In the absence of an external force, the body is in equilibrium and has zero acceleration. If the body is initially at rest , it remains at rest, if it is initially in motion, it continuously to move with constant velocity.

ewton’s 2nd law of motion

hen a net external force acts on a body, the body accelerates

$$\sum \vec{F} = m\vec{a} \, or \, \vec{a} = \frac{\sum \vec{F}}{m}$$

$$\sum \vec{F} = m\vec{a} = m\frac{d\vec{v}}{dt} = \frac{d\vec{p}}{dt}, where \, \vec{p} = mv \, (momentum)$$

In component form,

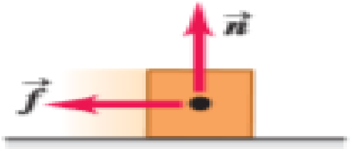
Newton’s 3rd law of motion

For every action there is an equal and opposite reaction both acts on two different bodies,

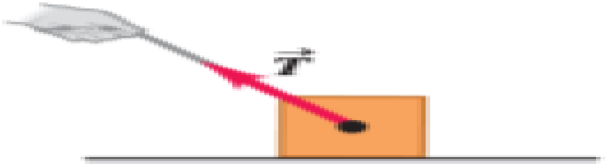
Four common types of forces in Mechanics

Normal force: *Directed perpendicular to the surface*

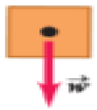
Frictional force: *Directed parallel to the surface that opposes slidi*



Tension force *(or pulling force)*



Gravitational force: *The force that earth exerts on the body (weight)*



Static and Kinetic Friction

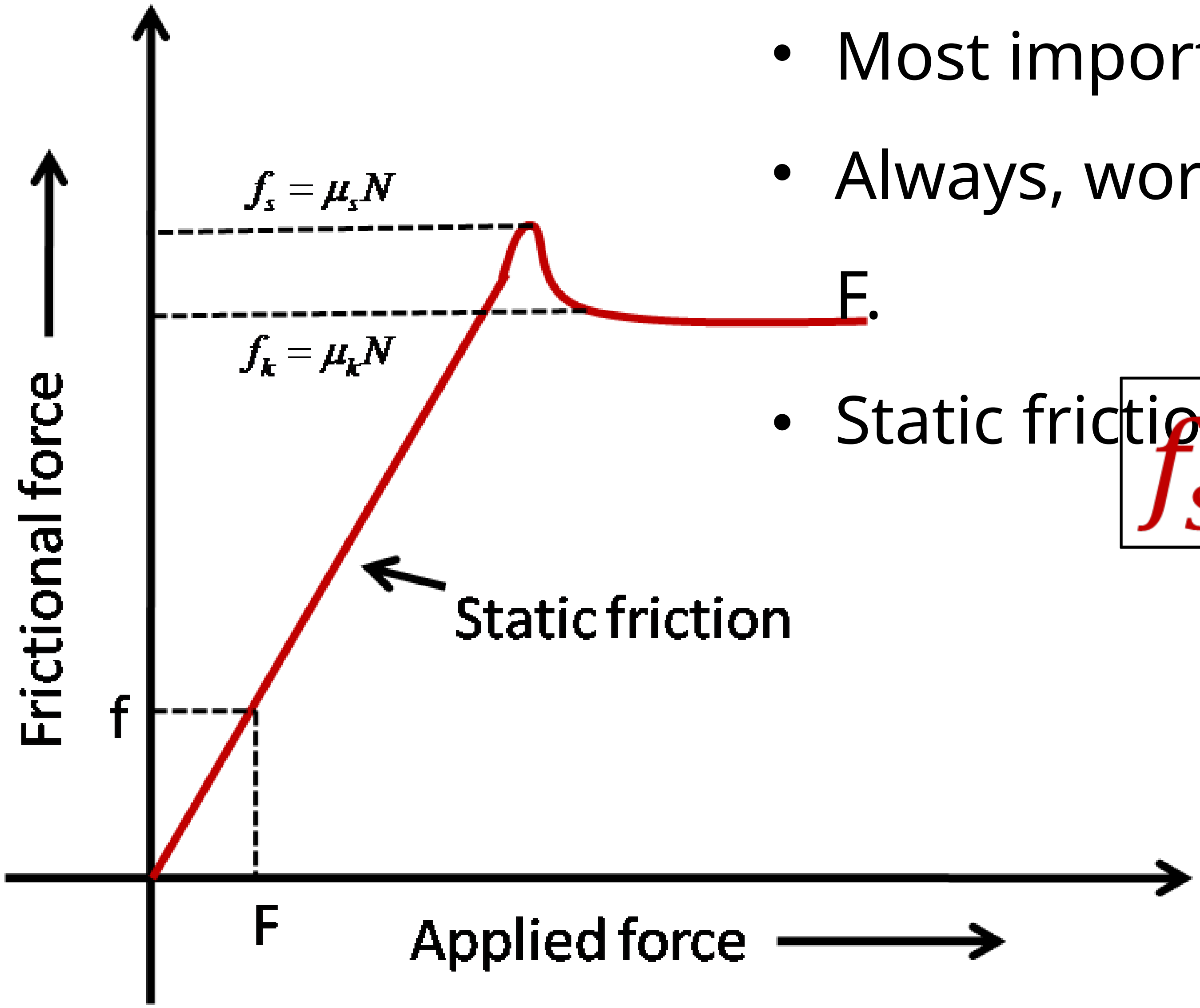
When the two objects are moving relative to each other; the friction in that case is called kinetic friction or sliding friction.

When the two surfaces are non-moving but there is still a lateral force as in the example of the block at rest on an inclined plane, the force is called, static friction.

$$\text{Friction} \propto \text{Normal force}$$

$$|\text{Friction}| = \text{Friction coefficient} * |\text{Normal force}|$$

Frictional force

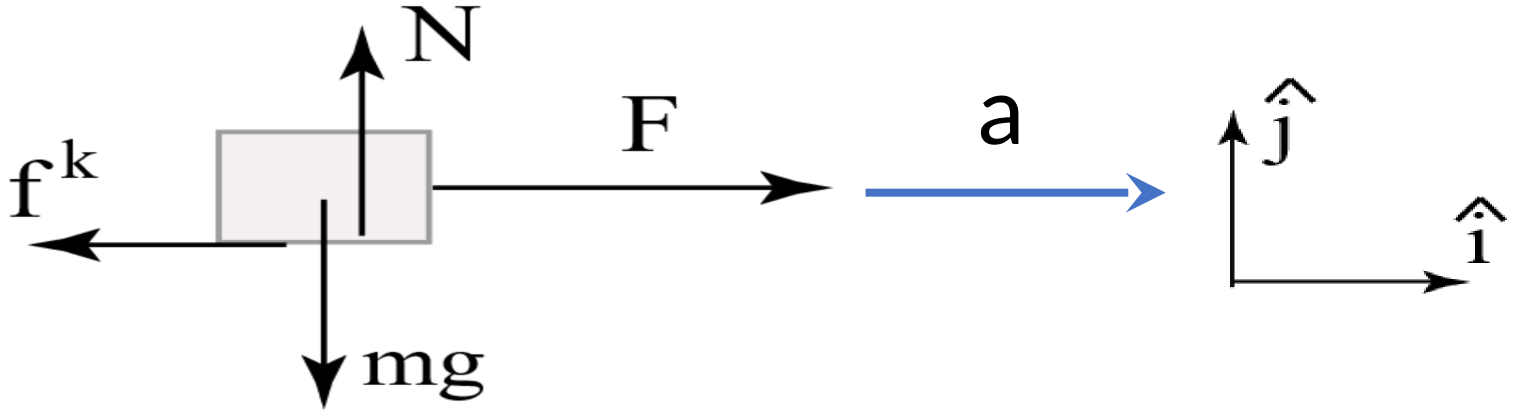


- Most important contact force in mechanics.
- Always, work opposite to the applied force F.
- Static friction (f_s) and kinetic friction (f_k)

$$f_s < f_s^{max} = \mu_s . N$$

$$f_k = \mu_k . N$$

Newton's law from free body diagram



$$a_x = a$$
$$a_y = 0$$

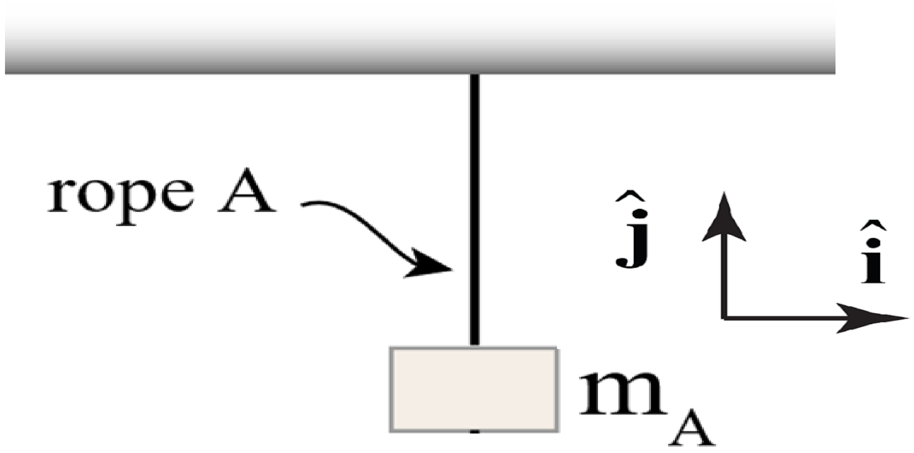
$$\sum F_x = ma_x$$
$$F - f_k = ma_x$$
$$F - \mu_k N = ma$$
$$F - \mu_k mg = ma$$

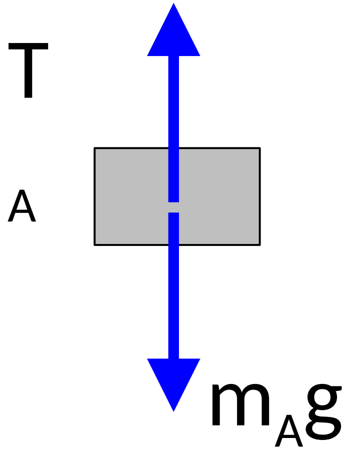
$$\sum F_y = ma_y$$
$$N - mg = ma_y$$
$$N = mg$$

since $a_y = 0$

$$a = \frac{F - \mu_k mg}{m} \Rightarrow F = ma + \mu_k mg \Rightarrow m = \frac{F}{(a + \mu_k g)} \Rightarrow \mu_k = \frac{F - ma}{mg}$$

Object hanging and at rest



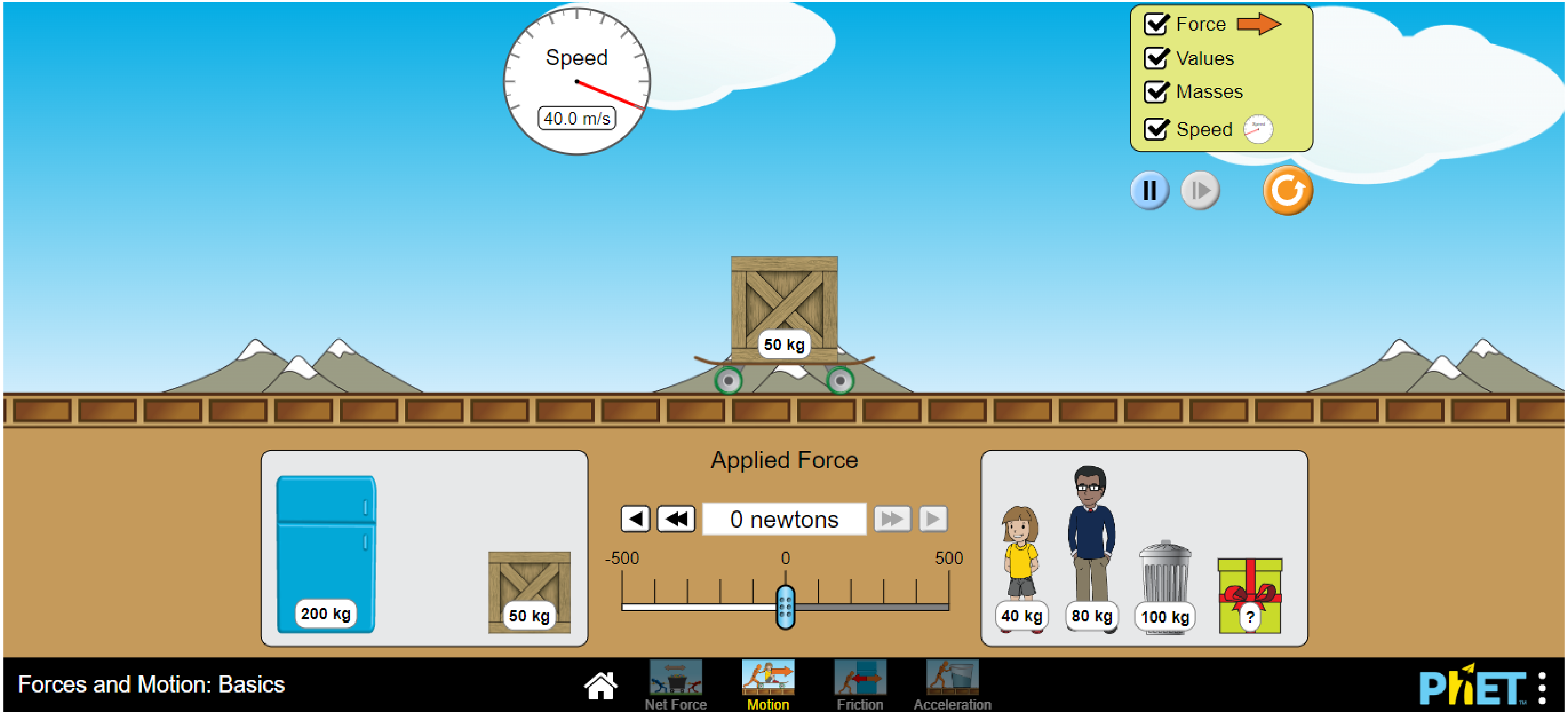


$$\sum \vec{F} = m\vec{a}$$

$$T_A - m_A g = 0$$
$$T_A = m_A g$$

The block pulls the rope down and the rope pull the block up.
This is true whether it is at rest or move upward/downward

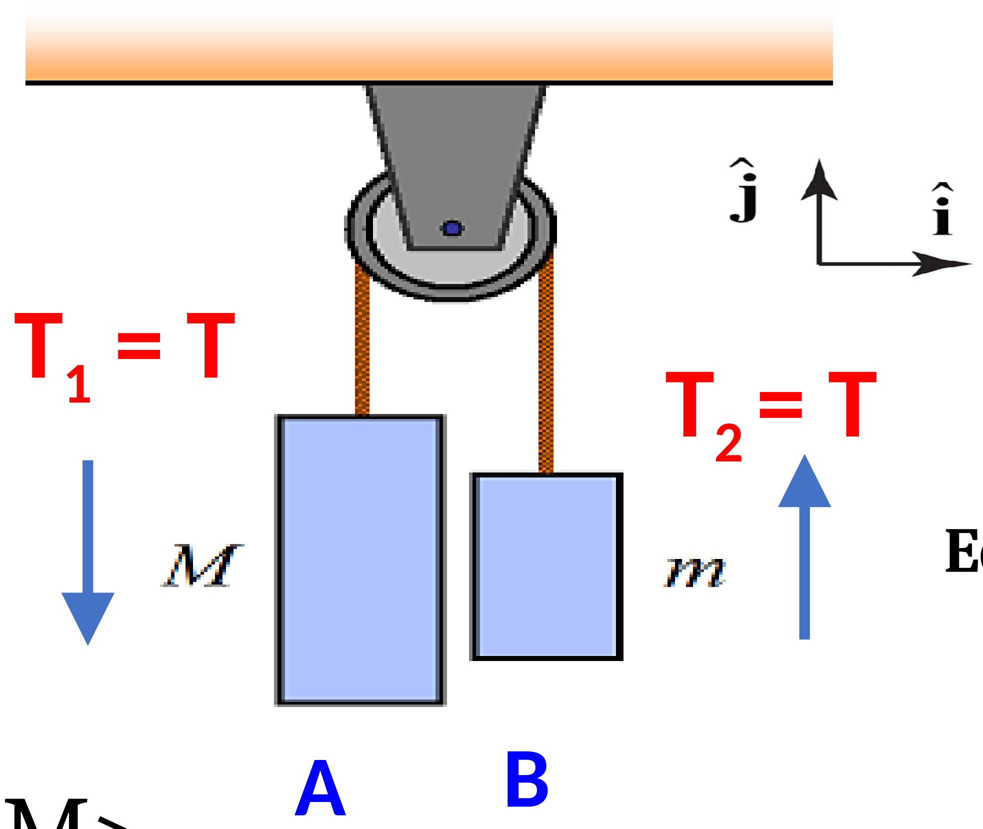
INTERACTIVE PRESENTATION

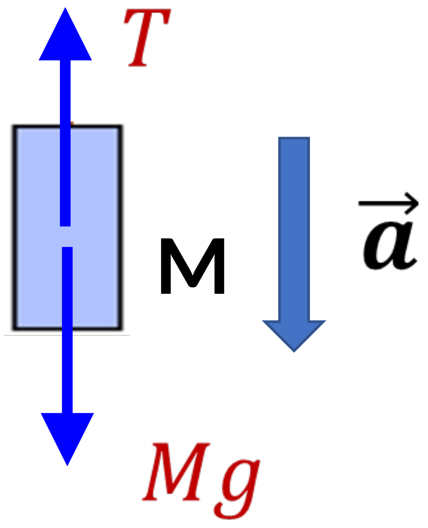


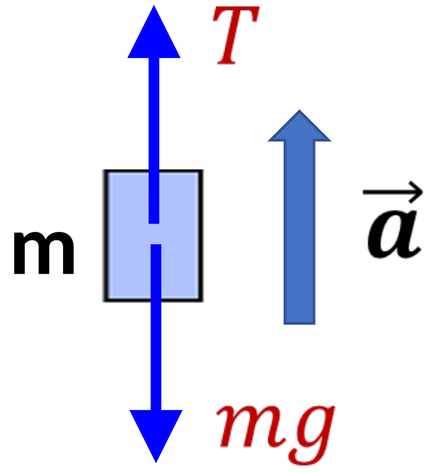
https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_en.html

Ideal Pulley system

- Rope-pulley is frictionless and **pulley at rest**.
- Rope/string is massless i.e., **uniform tension**.







Eqn 1

$$T - Mg = M(-a)$$

Eqn 2

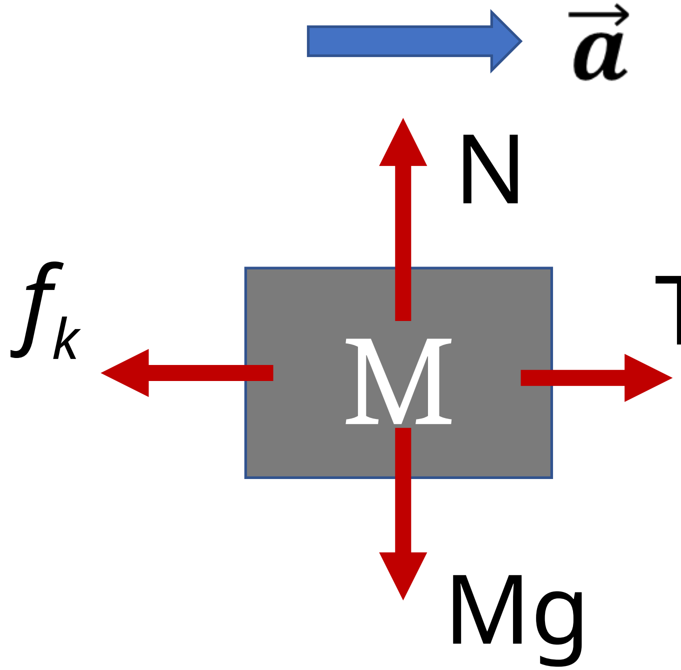
$$T - mg = m(+a)$$

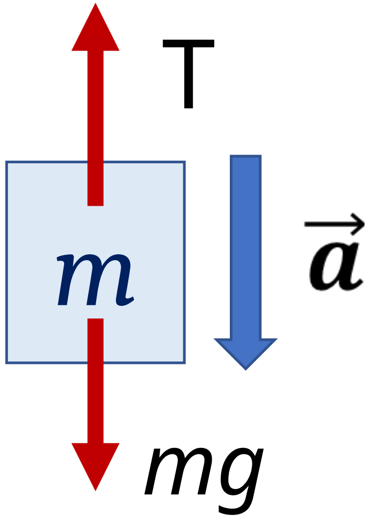
M> m

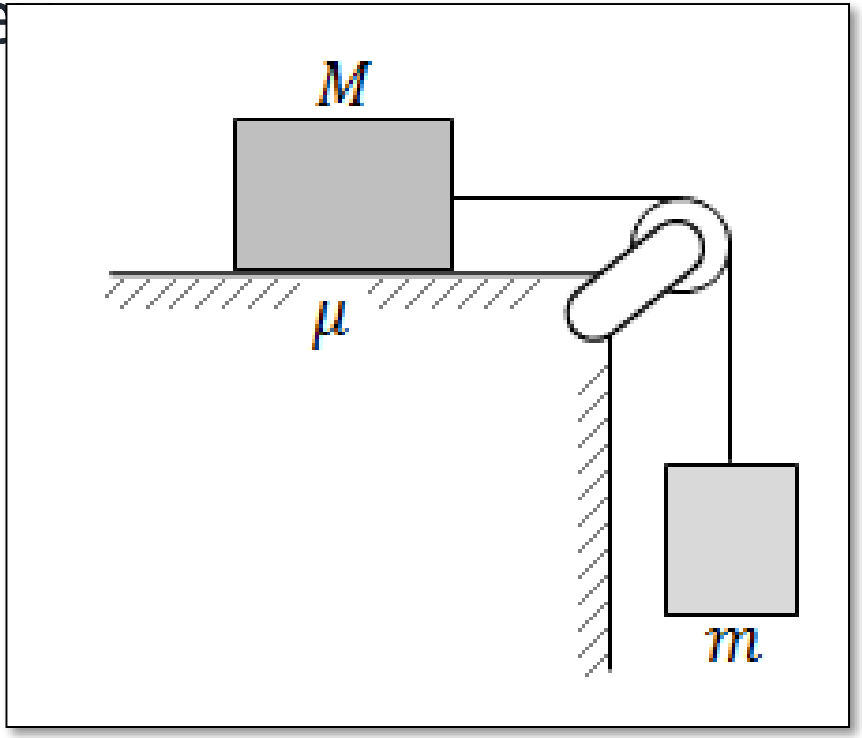
Equating T from Eqn 1 – Eqn2 $\Rightarrow$

$$\boldsymbol{a = \frac{(M - m)}{(M + m)} g}$$

Problem: Find the acceleration of the system of masses neglecting the mass of the string and the inertia of the pulle







$$Ma = T - f_k \ (1) \Rightarrow Ma = T - \mu_k N$$

$$m(-a) = T - mg \ (2)$$

$$a = \left(\frac{m - \mu_k M}{m + M}\right) g$$

QUIZ 01

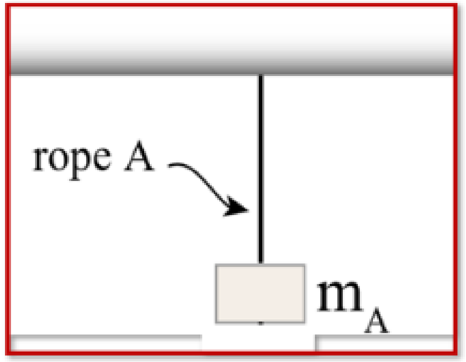
Calculate tension in the rope if weight of the block is 3Kg

A. 10 N

B. 20 N

C. 30 N

D. 40 N



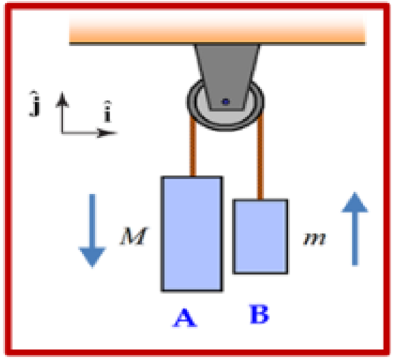
Calculate acceleration of the system when M_A = 2Kg and M_B = 1Kg

A. 0 m/s^2

B. 10/3 m/s^2

C. 20/3 m/s^2

D. 10 m/s^2



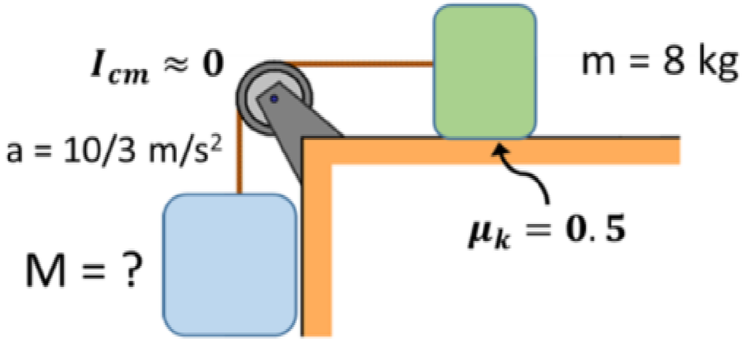
Find the mass M.

A. 3Kg

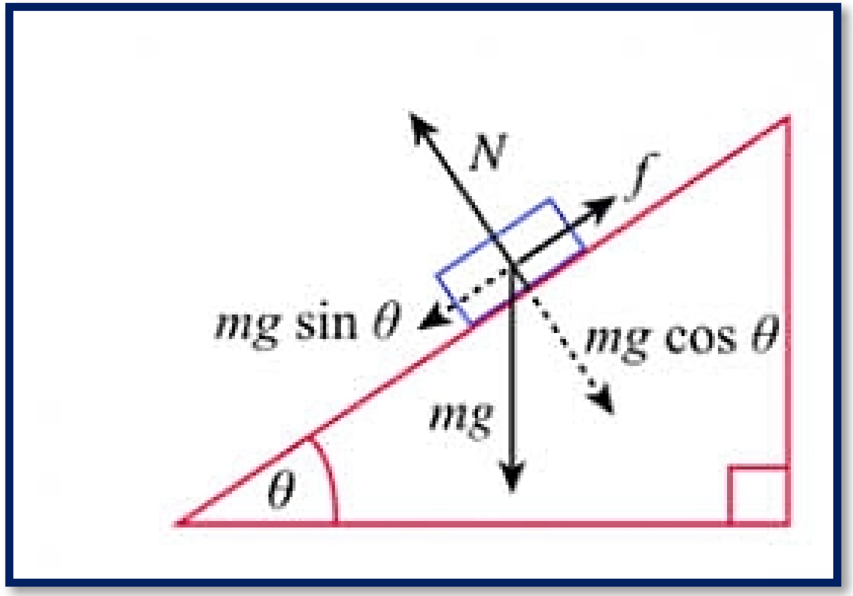
B. 5Kg

C. 7Kg

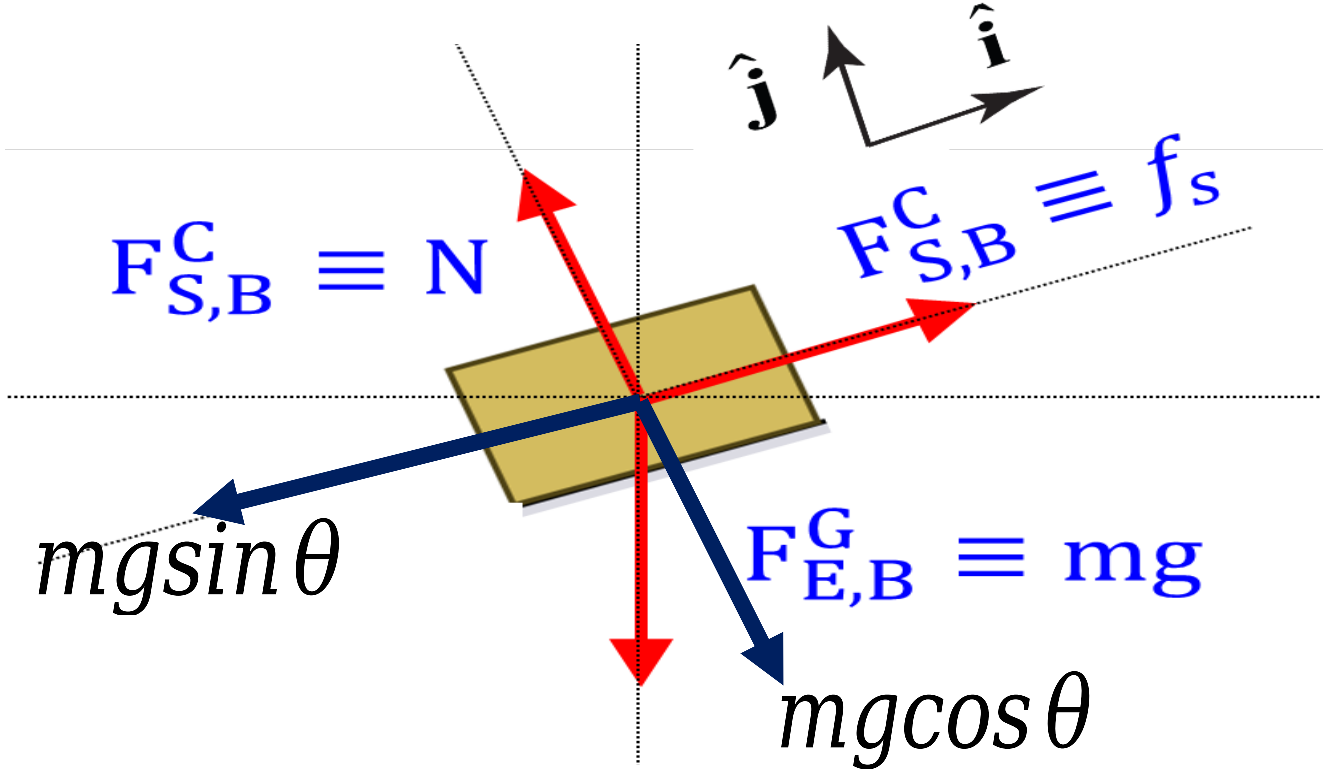
D. 10Kg



Object on an inclined plane



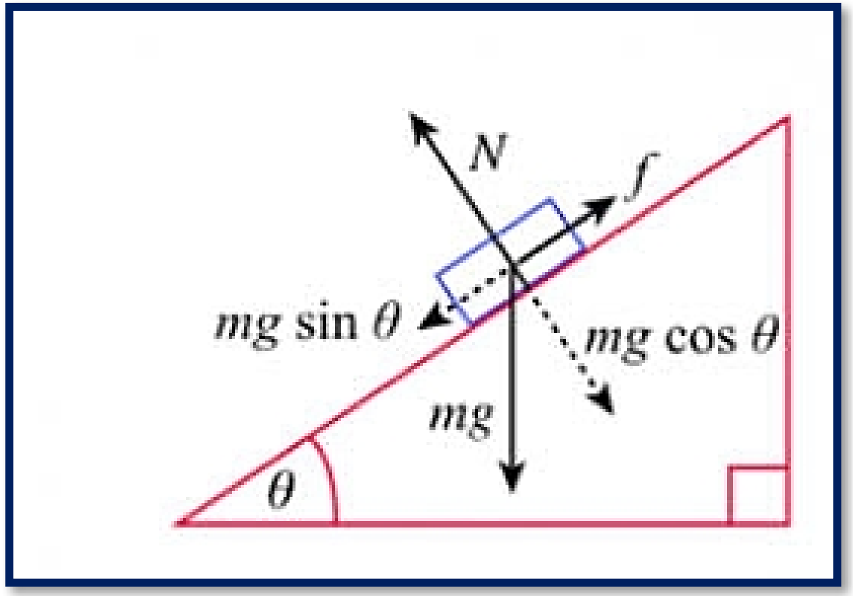
Free body force diagram:



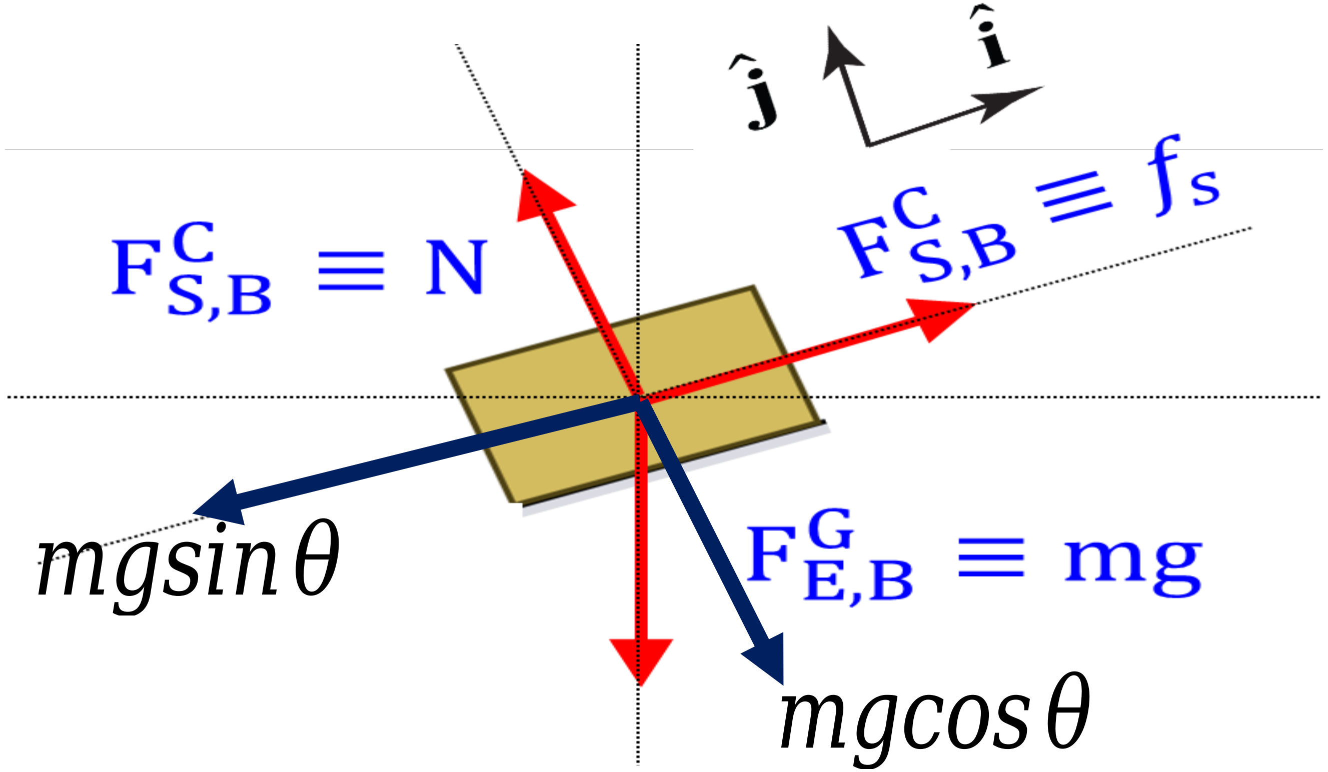
Find the generic expression for the static frictional force when the block is resting on an inclined plane with friction?

$$N = mgcos\theta \vee \sum F = ma = mgsin\theta - f_s \Rightarrow mgsin\theta - f_s = 0 \Rightarrow f_s = mgsin\theta$$

Object on an inclined plane



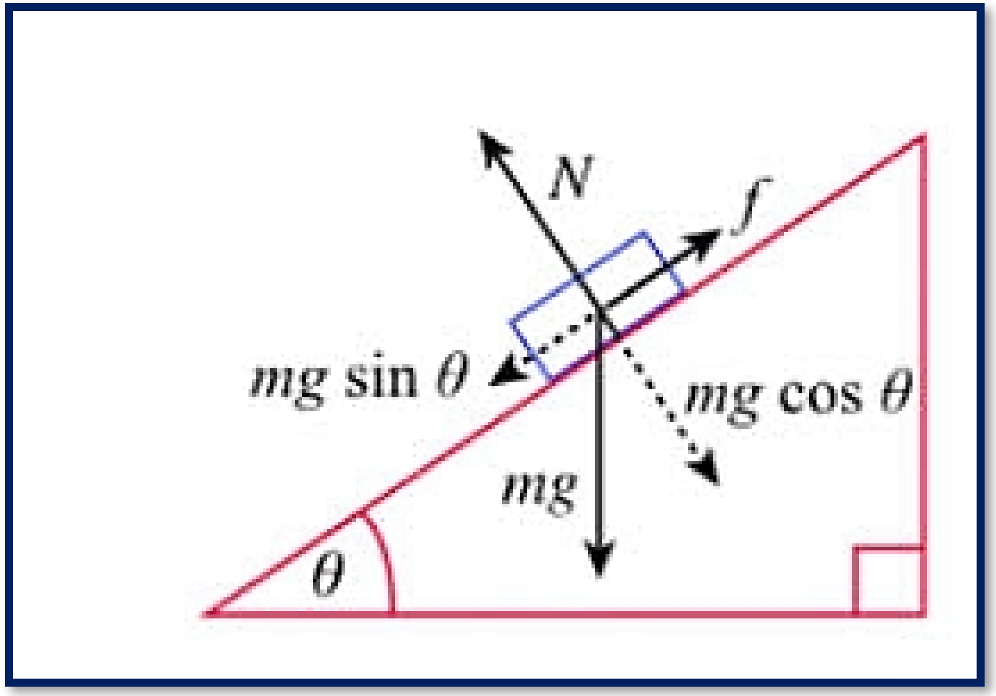
Free body force diagram:



Find the generic expression for the acceleration of a block slipping on an inclined plane with friction?

$$N = mgcos\theta \vee \sum F = ma = mgsin\theta - f_k \Rightarrow a = g\left(sin\theta - \mu_k cos\theta\right)$$

Object on an inclined plane

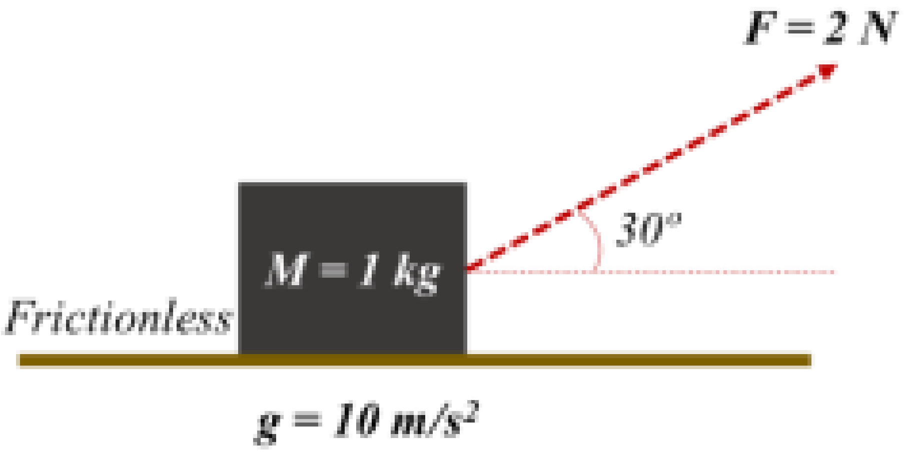


If the angle of the inclined plane can be varied, then at the object start to slide!

Practice problems

A block of mass *1 kg* is pulled by an external force of *2 N* *as shown in the figure*.

What will be the magnitude of normal force (N)?



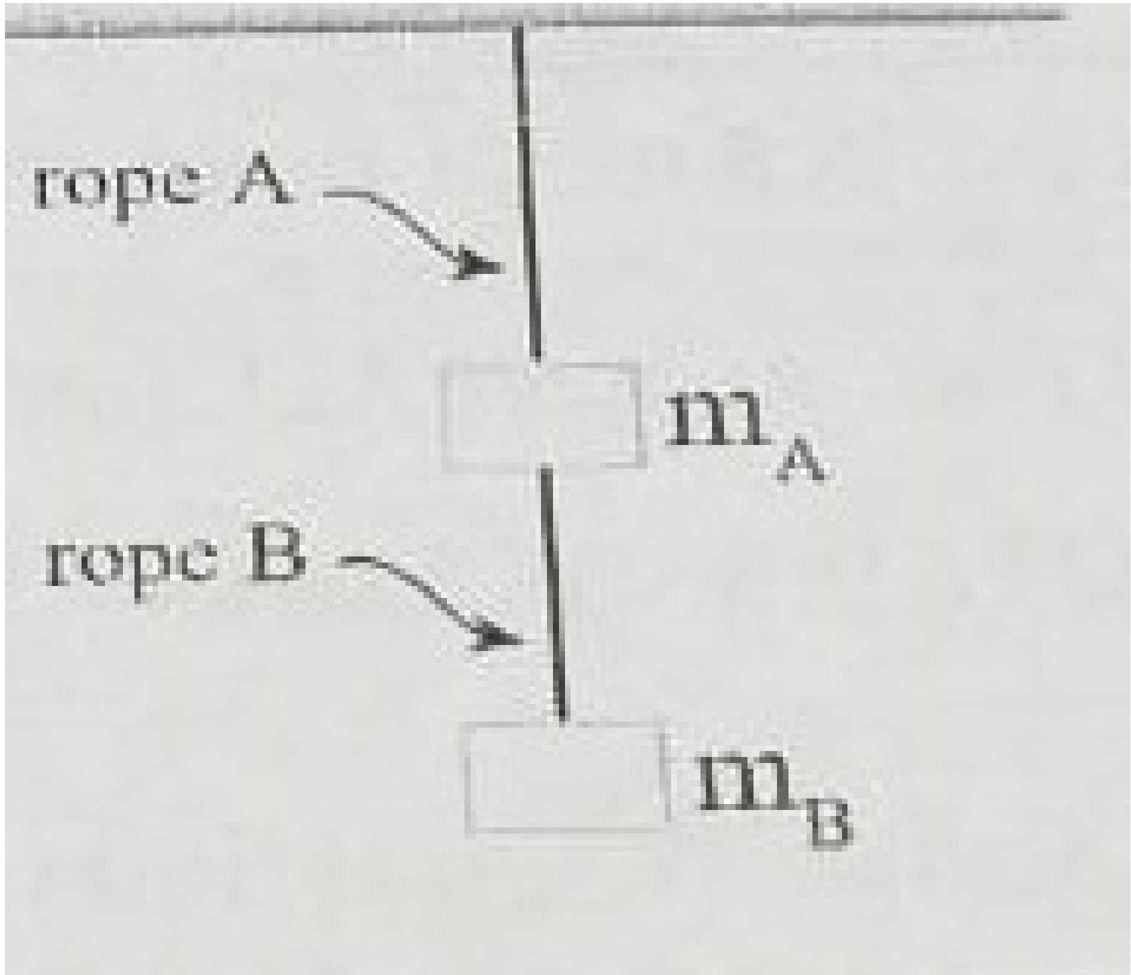
(a) 10 N

(b) 2 N

(c) 4 N

(d) 9 N

Calculate tension in the rope of A (T_A) and B (T_B) when m_A=3 kg and m_B = 5 kg.



LECTURE-03

Momentum and Impulse

CONCEPT QUESTION

In a football game a 70 kg player is running at 36 km/hr. When he is hit by the other player he bounces off in the opposite direction at 18 km/hr.

(a) What is the initial linear momentum of the player before this collision?

A. 350 Kg.m/s

B. 700 Kg.m/s

C. 1050 Kg.m/s

D. 1250 Kg.m/s

CONCEPT QUESTION

In a football game a 70 kg player is running at 36 km/hr when he is hit by another player. When he is hit by the other player he bounces off in the opposite direction at 18 km/hr.

(b) What is the final linear momentum of the player after this collision?

A. 350 Kg.m/s

B. 900 Kg.m/s

C. 1050 Kg.m/s

D. 1250 Kg.m/s

CONCEPT QUESTION

In a football game a 70 kg player is running at 36 km/hr when he is hit by another player. When he is hit by the other player he bounces off in the opposite direction at 18 km/hr.

(c) What is the change of linear momentum in this collision?

A. 350 Kg.m/s

B. 900 Kg.m/s

C. 1050 Kg.m/s

D. 1250 Kg.m/s

$$P_f - P_i = m\left(v_f - v_i\right) = 70\left[5 - \left(-10\right)\right] = 1050\,Kg\,m$$

Linear Momentum (P)

Momentum of an object is defined as the product of its mass and velocity

Momentum is a vector quantity. The direction of momentum is same as the direction of velocity

- If the particle has velocity components v_x, v_y, v_z and then its momentum components p_x, p_y, p_z

(can be called *x-momentum, y-momentum, and z-momentum) are* given by

$$p_x = mv_x ; p_y = mv_y ; p_z = mv_z$$

From Newton' s second law

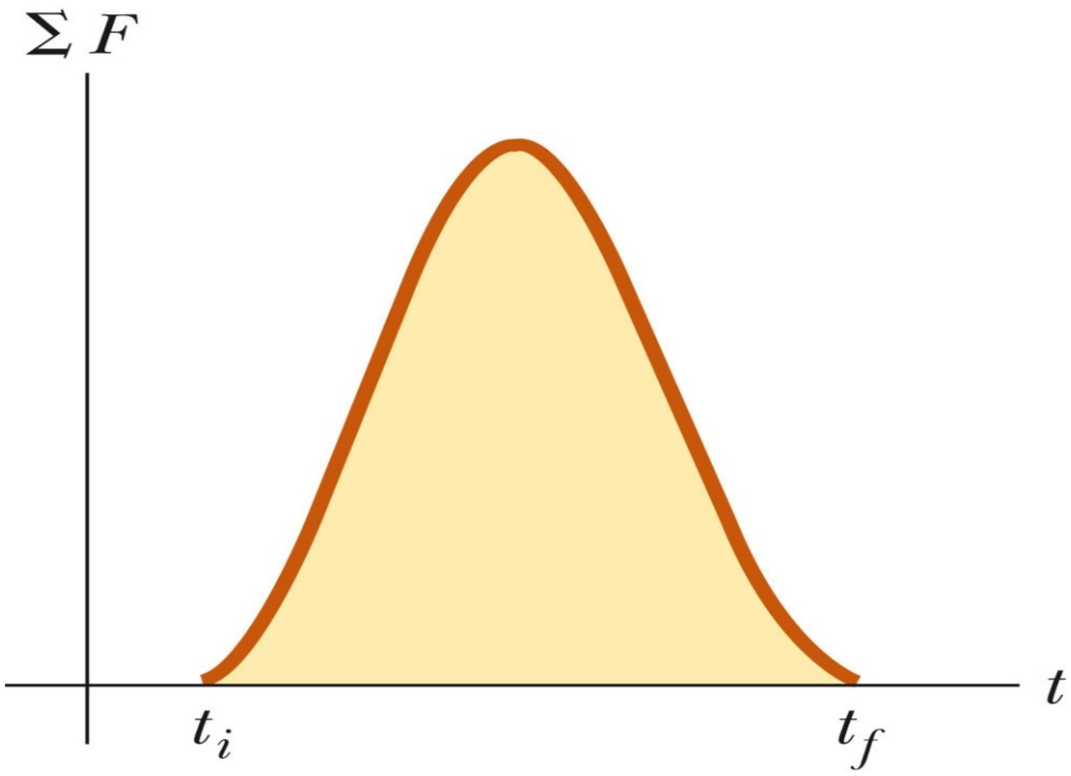
$$\sum \vec{F} = m\vec{a} = m\frac{dv}{dt} = \frac{d(mv)}{dt} = \frac{dp}{dt}$$

The net force (vector sum of all forces) acting on a particle is equal to the time rate of change of momentum of the particle

Impulse

- Impulse is a vector quantity
- The magnitude of the impulse is equal to the area under the force-time curve
- The force may vary with time
- Dimensions of impulse are **M L / T**
- Impulse is not a property of the particle, but a measure of the change in momentum of the particle

$$\int_{t=t_i}^{t=t_f} \vec{F}(t).dt = \vec{I}$$



Unit => Kg m/s

Impulse-momentum theorem

- Consider a particle acted on by a *constant net force* during a time interval *Δt* from to . *The impulse of the net force*, denoted by **I** is defined to be the *product of the net force and the time interval.*

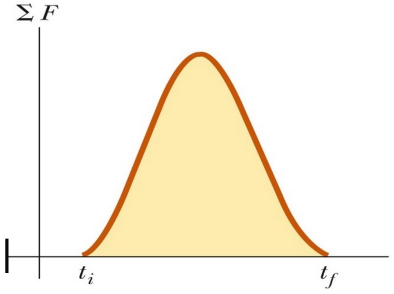
- From Newton’ s second law,
-)=

$$p_{fx} - p_{ix} = \Delta p_x = I_x$$
$$p_{fy} - p_{iy} = \Delta p_y = I_y$$
$$p_{fz} - p_{iz} = \Delta p_z = I_z$$

The change in momentum of a particle during a time interval equals the impulse of the net force acting on the particle during that interval.

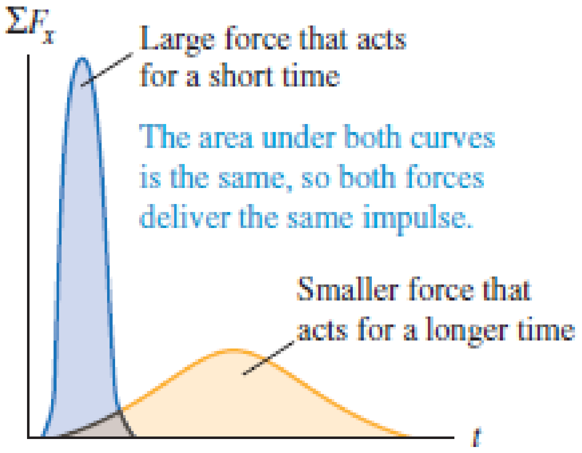
- The force may vary with time. The magnitude of the impulse is equal to the area under the force-time curve.

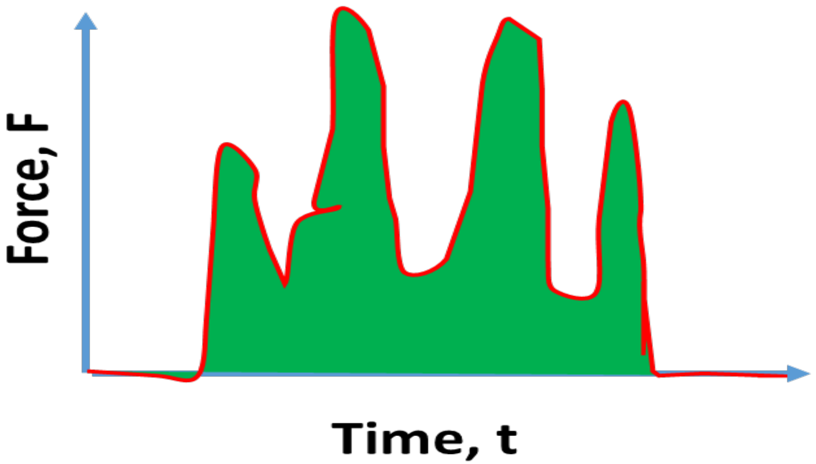
Force-momentum-impulse

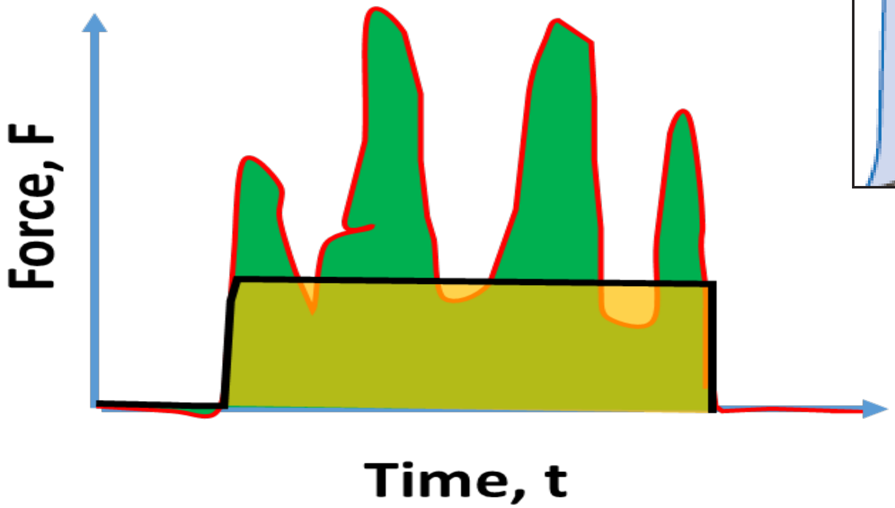


- The impulse–momentum theorem also holds when forces are not co

$$\int_{t=t_i}^{t=t_f} \vec{F}(t).dt = \vec{F}_{av}.\Delta t = I$$







POLL QUESTION

In a football game a 70 kg player is running at 36 km/hr when he is hit by another player. When he is hit by the other player he bounces off in the opposite direction at 18 km/hr.

(a) What is the Impulse felt by the player?

A. 950 Kg.m/s

B. 1000 Kg.m/s

C. 1050 Kg.m/s

D. 1100 Kg.m/s

Impulse is equal to change in momentum

POLL QUESTION

In a football game a 70 kg player is running at 36 km/hr when he is hit by another player. When he is hit by the other player he bounces off in the opposite direction at 18 km/hr.

(b) When the two players collide, there contact took 0.05 seconds. What average force was exerted by each player in the collision?

A. 15000N

B. 17000N

C. 19000N

D. 21000N

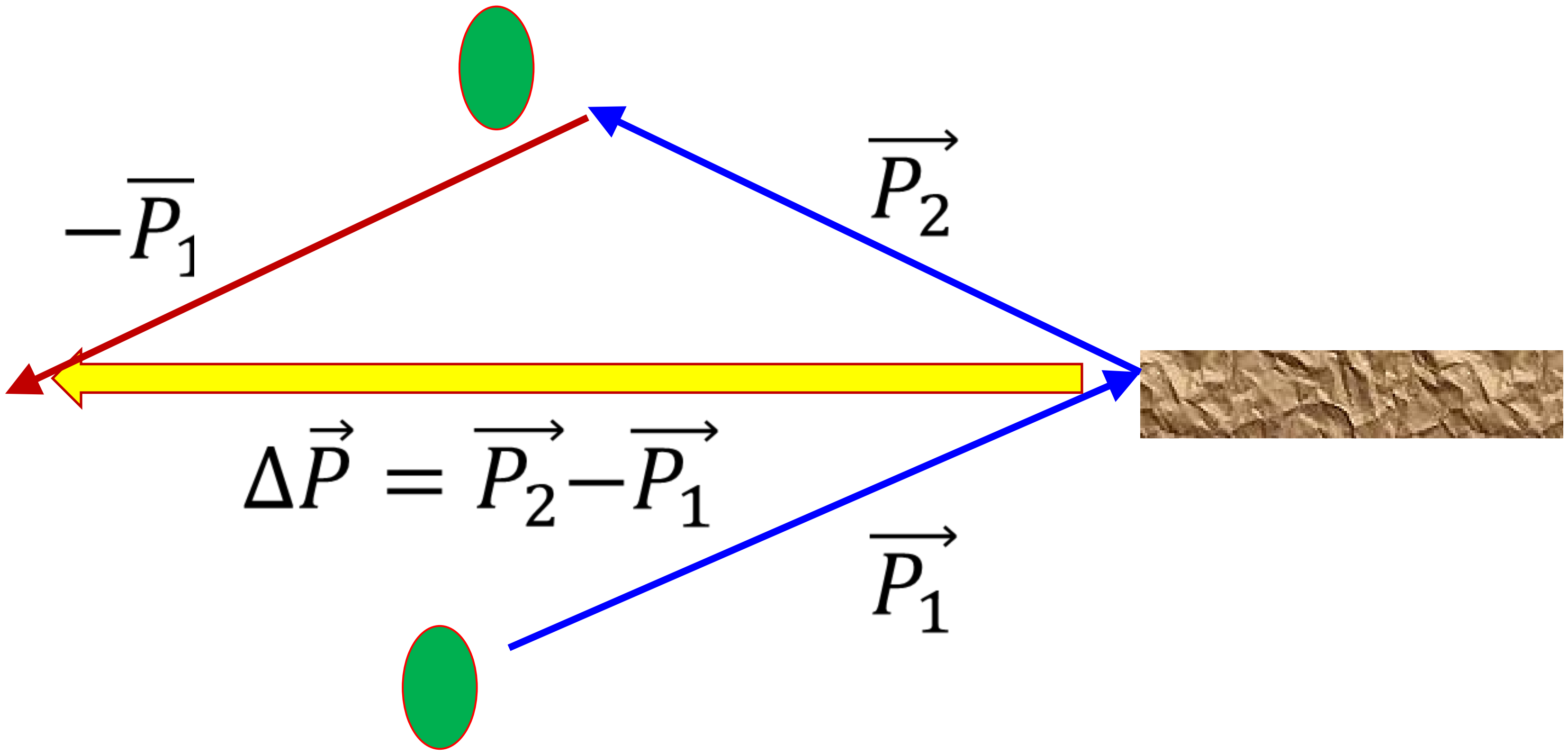
Impulse is equal to change in momentum

Collision time,

Thus *average horizontal force* =

Solved Example

Draw the impulse vector.



POLL QUESTION

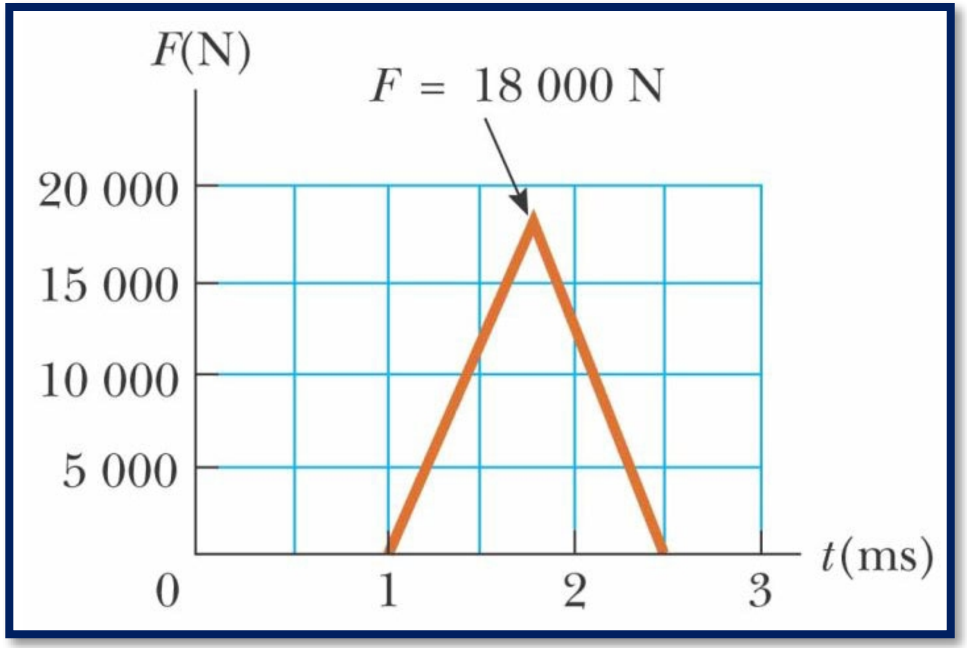
An estimated force-time curve for a cricket ball by a bat is shown in Figure. From this curve, determine the impulse delivered to the ball

A. 11.3 N.s

B. 13.5 N.s

C. 17.6 N.s

D. 19.4 N.s



Impulse

POLL QUESTION

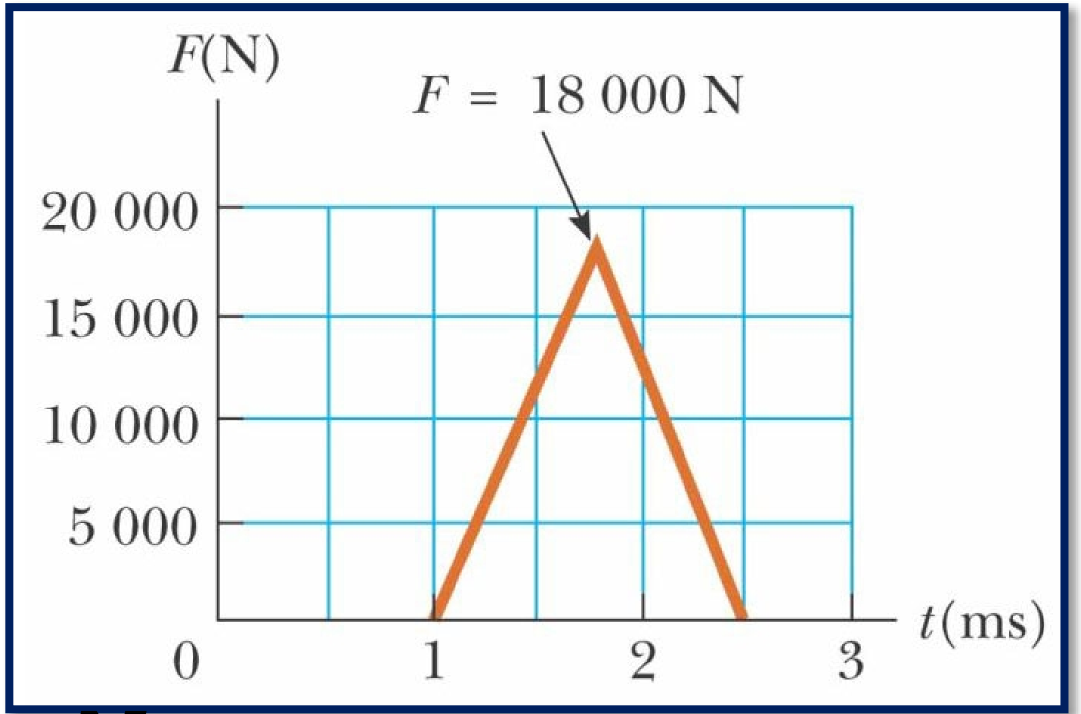
An estimated force-time curve for a cricket ball by a bat is shown in Figure. From this curve, determine the average force exerted on the ball.

A. 5000N

B. 7000N

C. 9000N

D. 12000N



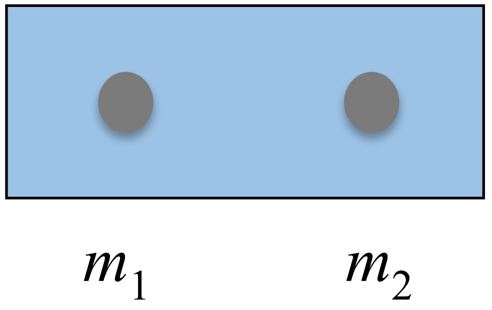
$$F_{avg} = \frac{I}{t} = \frac{13.5}{1.5 \times 10^{-3}} = 9000\,N$$

Conservation of Linear Momentum

If no net external force acts on a system of particles, the total linear momentum, **P**, of the system cannot change.

$$\frac{d\vec{P}}{dt} = \sum_{i}^{n} \frac{d\vec{p}_i}{dt} = \vec{F}_{ext} = 0$$

If the component of the net external force on a closed system is zero along an axis, then the component of the linear momentum of the system along that axis cannot change.



Newton's 3rd law

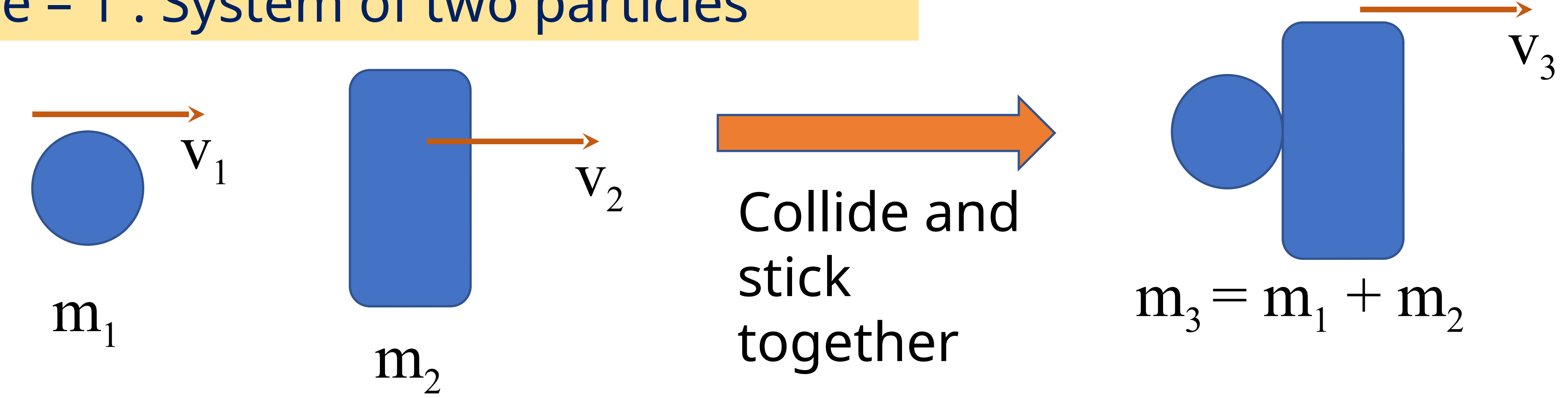
$$\frac{d\vec{p}_1}{dt} = -\frac{d\vec{p}_2}{dt} \qquad \frac{d(\vec{p}_1 + \vec{p}_2)}{dt} = \frac{d\vec{P}}{dt} = 0$$

Net internal force acting on system of particles is zero

For a system of particles $\frac{d\overrightarrow{P_{Sys}}}{dt} = \sum_{i}^{n} \frac{d\vec{p}_i}{dt} = \vec{F}_{ext} = 0$

If no external force is applied on the system $\vec{P}_{sys} = Constant$

Case – 1 : System of two particles



$$\vec{P}_{sys}(initial) = \vec{P}_{sys}(final)$$

$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}_3$$

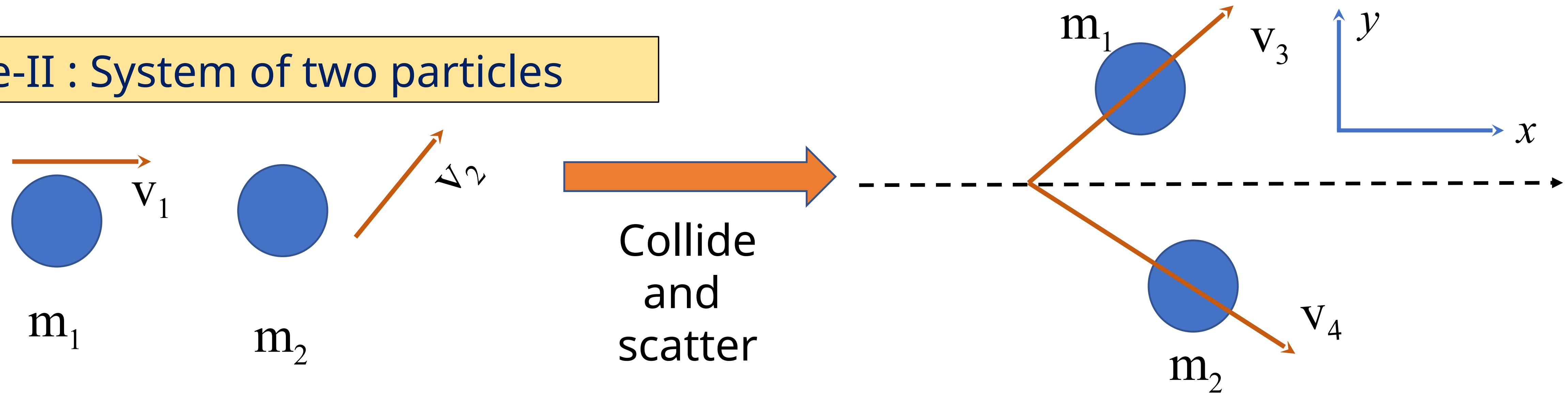
Change in Momentum after collision

$$\Delta\vec{P}_{sys} = \vec{P}_{sys}(final) - \vec{P}_{sys}(initial)$$

If collision is sustained for time Δt, then Impulse

$$\vec{F}_I = \Delta\vec{P}_{sys} = \vec{F}_{avg} \times \Delta t$$

Case-II : System of two particles



$$\vec{P}_{sys}(initial) = \vec{P}_{sys}(final)$$

$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_3 + m_2\vec{v}_4$$

$$\Downarrow$$

$$m_1 v_{1x} + m_2 v_{2x} = m_1 v_{3x} + m_2 v_{4x}$$

$$m_1 v_{1y} + m_2 v_{2y} = m_1 v_{3y} + m_2 v_{4y}$$

POLL QUESTION

Two cars collide while going in the same direction. Car A has a mass of 1000 kg, velocity 5 m/s whereas car B has a mass of 2000 kg and velocity 2 m/s. After collision, car A continues to move at 3 m/s, then what is the speed of car B after the collision?

A. 3m/s

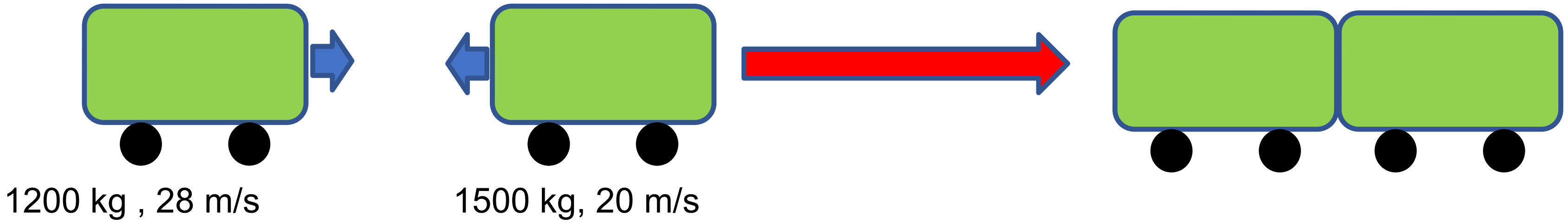
B. 5m/s

C. 7m/s

D. 11m/s

POLL QUESTION

Two cars collide in a head on collision as shown in figure. They lock together.
a. What is the speed and direction of the two cars after the collision?



A. 1.15m/s

B. 2.23m/s

C. 1.33 m/s

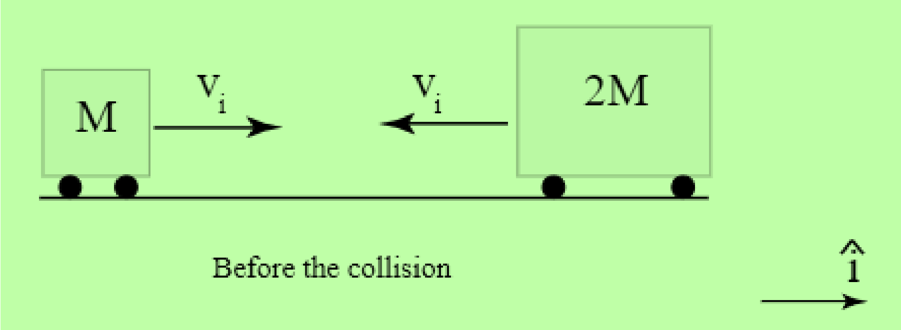
D. 4.34 m/s

1.33 m/s

Practice problems

Short Problems on *Momentum conservation in 1D*

- Two cars of mass *M* and *2M* are moving along a horizontal and frictionless surface in opposite directions with speed V_i. After the collision they stick together.



What is final velocity v_f?

$$\begin{aligned} \vec{p}_f &= \vec{p}_i \\ 3M\vec{v}_f &= -Mv_i\,\hat{i} \\ \vec{v}_f &= -\frac{v_i}{3}\,\hat{i} \end{aligned}$$

Short Problems on *Momentum conservation in 1D*

A 15-g (0.015-kg) bullet is fired from a 5-kg rifle at a muzzle velocity of 600 m/s. Find the recoil velocity of the rifle.

Mass of the rifle, M = 5 kg
Mass of the **bullet**, m = 15 g = 0.015 kg
Velocity of the bullet **afterwards**, v_2 = 600 m/s
The **momentum** of the bullet and **riffle** before shooting will be **equal** to the momentum of
Since, before **shooting** the bullet was in the **riffle** and the **velocity** of both was 0,

$$M(0) + m(0) = Mv_1 + mv_2$$

$$-Mv_1 = mv_2$$

$$v_1 = -\frac{m \times v_2}{M}$$

Substitute the values,

$$v_1 = -\frac{0.015 \times 600}{5}$$

$$v_1 = -1.8 \text{ m/s}$$

Thus, the **recoil** of the rifle is -1.8 m/s, the **negative** sign denotes that the velocity of **recoil** was in **opposite direction** to the bullet.

Short Problems on *Momentum conservation in 1D*

2.

An 8.0-g bullet is fired horizontally into a 9.00-kg cube of wood, which is at rest, and sticks in it. The cube is free to move and has a speed of 40 cm/s after impact. Find the initial velocity of the bullet.

Consider the system (cube + bullet). The velocity, and hence the momentum, of the cube before impact is zero. Take the bullet's initial motion to be positive in the positive x-direction. The momentum conservation law tells us that

$$\text{Momentum of system before impact} = \text{momentum of system after impact}$$

$$(\text{momentum of bullet}) + (\text{momentum of cube}) = (\text{momentum of bullet} + \text{cube})$$

$$m_B v_{Bx} + m_C v_{Cx} = (m_B + m_C) v_x$$

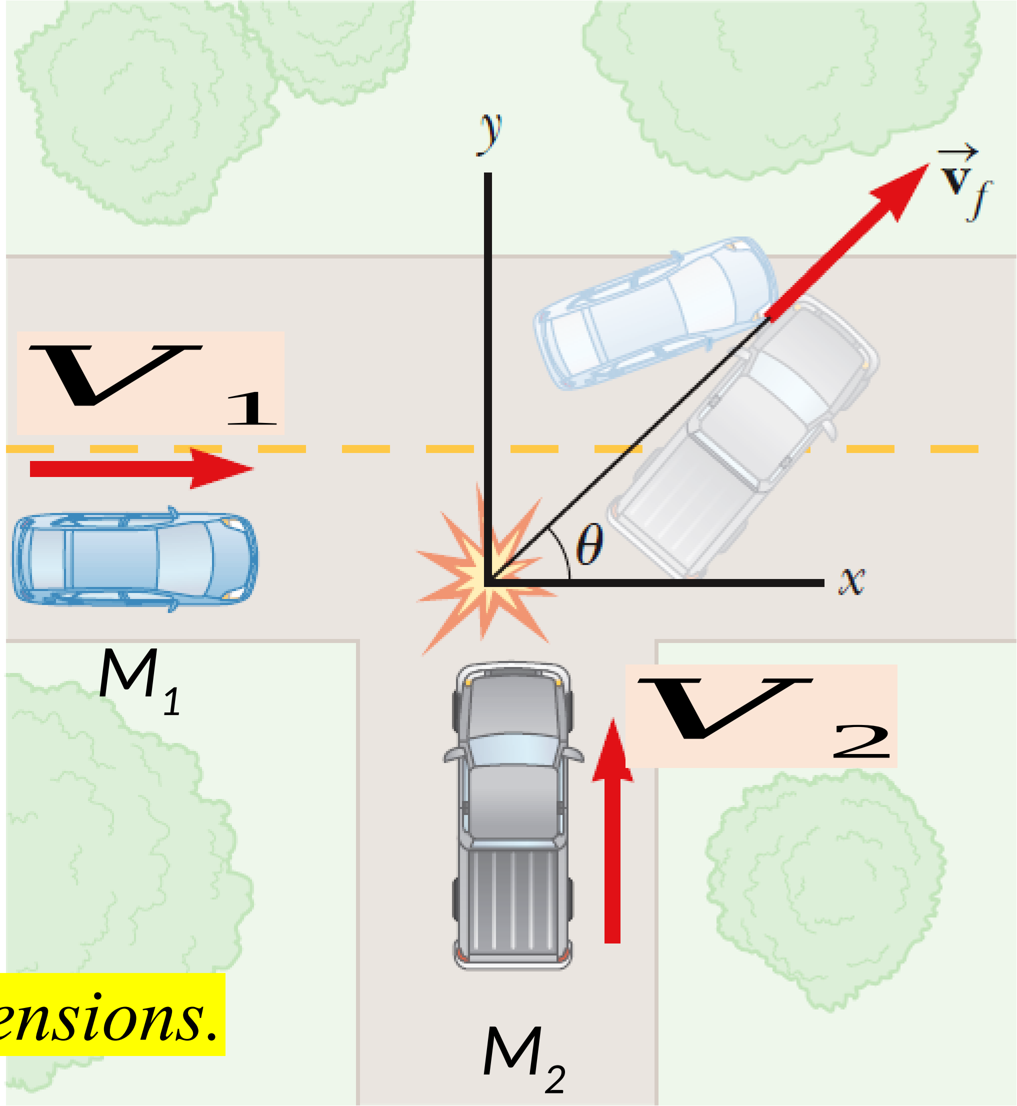
$$(0.0080 \text{ kg}) v_{Bx} + 0 = (9.008 \text{ kg})(0.40 \text{ m/s})$$

Solving gives $v_{Bx} = 0.45$ km/s and so $\vec{v}_B = 0.45$ km/s — POSITIVE X-DIRECTION.

Problem on Collision in 2D

Q. A car of mass M_1 traveling east with a speed of V_1 collides at an intersection with a truck of mas M_2 traveling north at a speed of V_2.

1. Calculate θ, the angle between the final velocity and the x-axis for the particular case when $M_2=2M_1$ and $V_2=/2$
   Express your answer in degrees.



Hint: *Apply momentum conservation in two dimensions.*

Ans: θ =

Given mass of an object is 2 kg and the velocity of the object is given by
Calculate its momentum. Find the force experienced by the object at t =2 s.

Q4.

a) $m = 2\ kg$, $\vec{v} = 2t\,\hat{i} + t^2\,\hat{j}$

$$\vec{p} = m\vec{v} = 2(2t\,\hat{i} + t^2\,\hat{j})$$

$$\Rightarrow \quad \vec{p} = 4t\,\hat{i} + 2t^2\,\hat{j}$$

b) $$\vec{F} = \frac{d\vec{p}}{dt} = 4\,\hat{i} + 4t\,\hat{j}$$

$$\vec{F}\Big|_{t=2s} = 4\,\hat{i} + 8\,\hat{j}$$

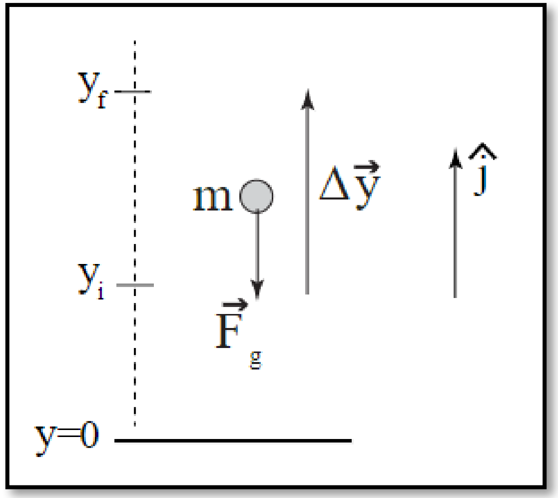
and $$|\vec{F}|_{t=2s} = \sqrt{4^2+8^2} = 8.94\ N$$

LECTURE-04

Work and Kinetic Energy

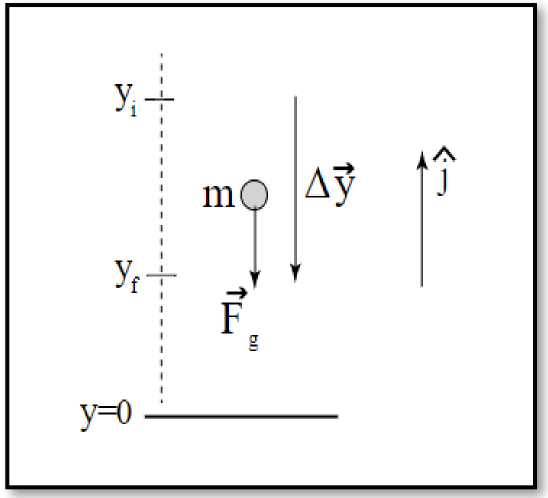
CONCEPT QUESTION

An object of mass m on the surface of the earth. Suppose the object moves vertically between two points at heights y_i and y_f as measured from the surface of the earth.



(a) What is the work done by gravity if the object is moving **up** from y_i to y_f ?

(b) What is work done by gravity if the object is moving **down** from y_i to y_f ?



Ans:

(a) $W_{i\to f} = mg(y_f - y_i)\, Cos\theta, \theta = 180^0 , W_{i\to f} < 0$

(b) $W_{i\to f} = mg(y_f - y_i)\, Cos\theta, \theta = 0^0, W_{i\to f} > 0$

CONCEPT QUESTION

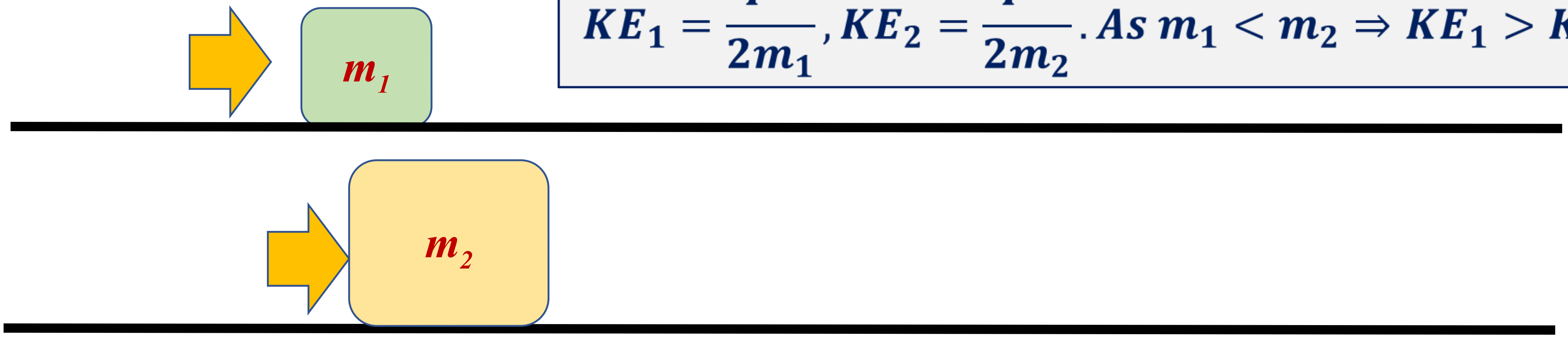
Two carts of masses ***m_1* and *m_2 (=2m_1)*** are at rest on a horizontal and frictionless surface. Both cars are pushed with equal forces for the same time interval.

At the end of the time interval, which mass of cart will have larger kinetic energy?

Ans: Cart with mass m_1.

$$KE = \frac{P^2}{2m}, \text{Same Impulse so same P (lin. mom.).}$$

$$KE_1 = \frac{P^2}{2m_1}, KE_2 = \frac{P^2}{2m_2}. As\ m_1 < m_2 \Rightarrow KE_1 > KE_2$$



Work done by a constant force

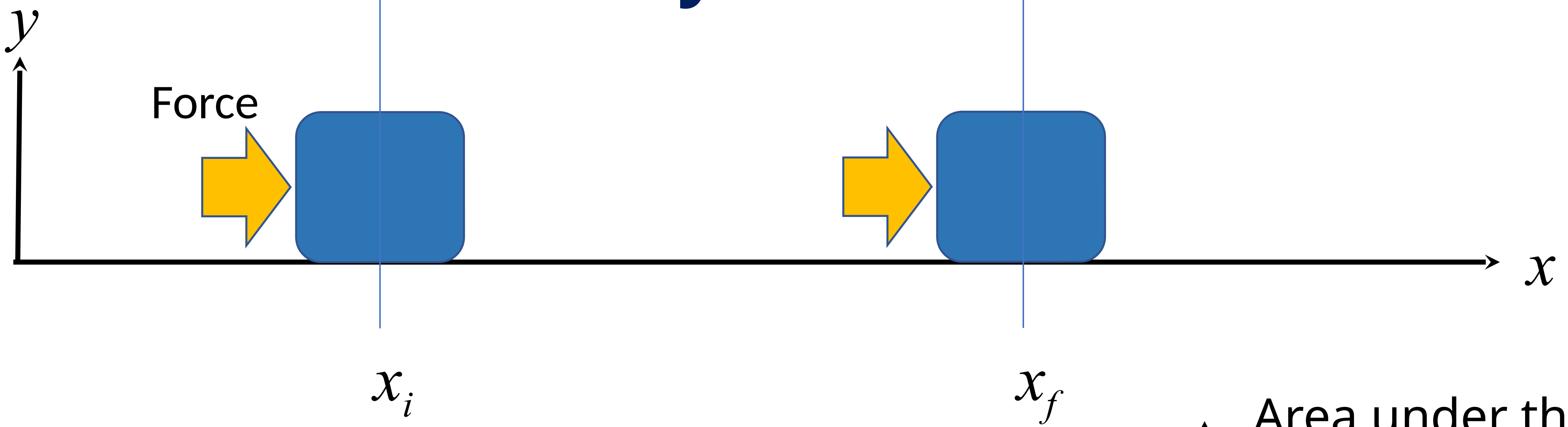
- The force is said to be constant force, when the direction and magnitude of it remain constant during displacement. Work is a scalar

- A constant force can do *positive, negative or zero work* depending on the angle between force and displacement.
- *When $\theta = 0$, and when $\theta = 90°$, $W = 0$*
- *Total work, when several forces act on a body?*

✓ One way is the algebraic sum of the quantities of work done by the individual forces.

✓ Alternative way to find the total work is to compute the vector sum of the forces (net force) and use the vector sum in

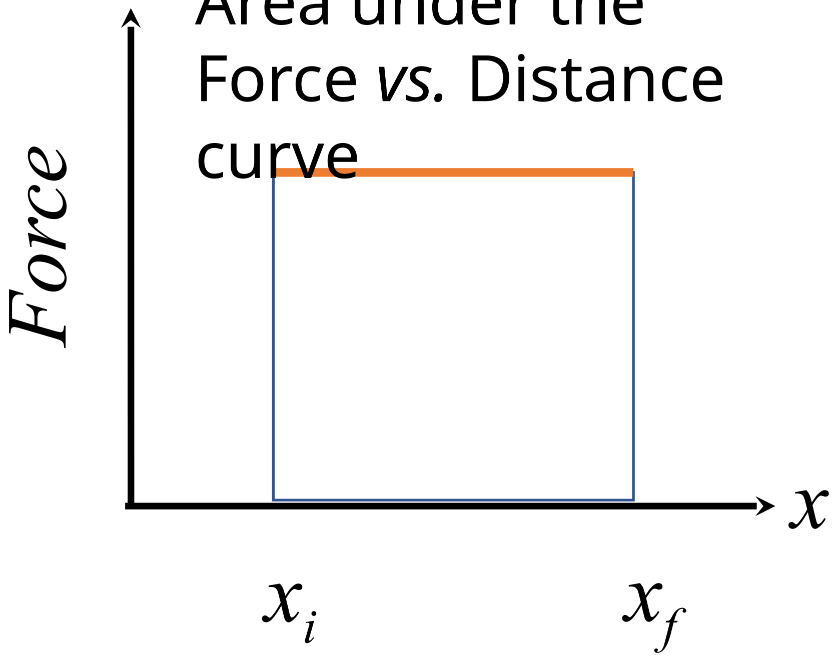
Work by a Constant Force



Work by a Constant Force $\vec{F}$ is **W**

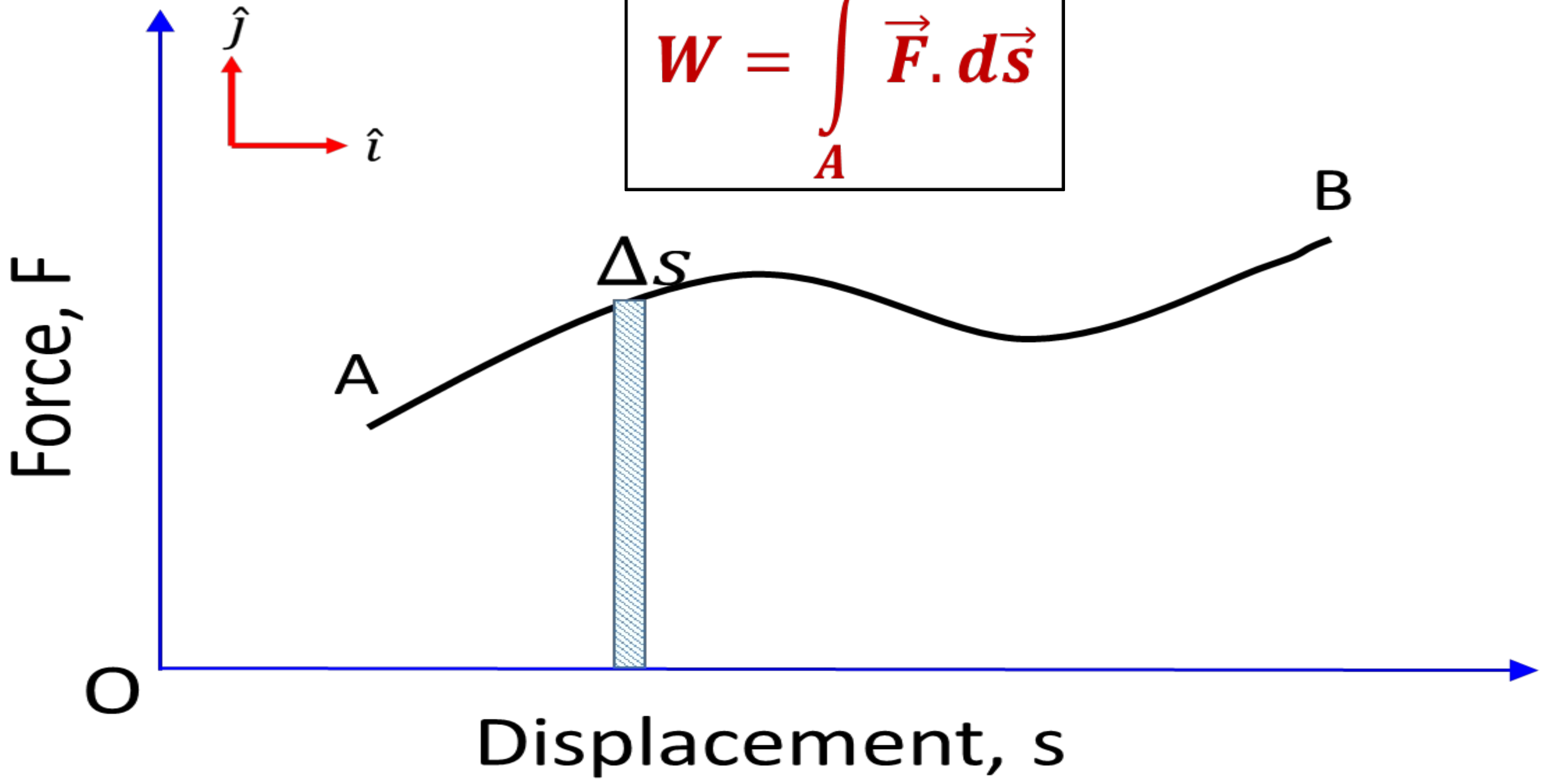
$$\boldsymbol{W} = \vec{\boldsymbol{F}}.(\overrightarrow{\boldsymbol{x_f}} - \overrightarrow{\boldsymbol{x_i}})$$

The SI unit of work is the *Joule (J)*, which is defined as the work expended by a force of one newton through a displacement of one metre.



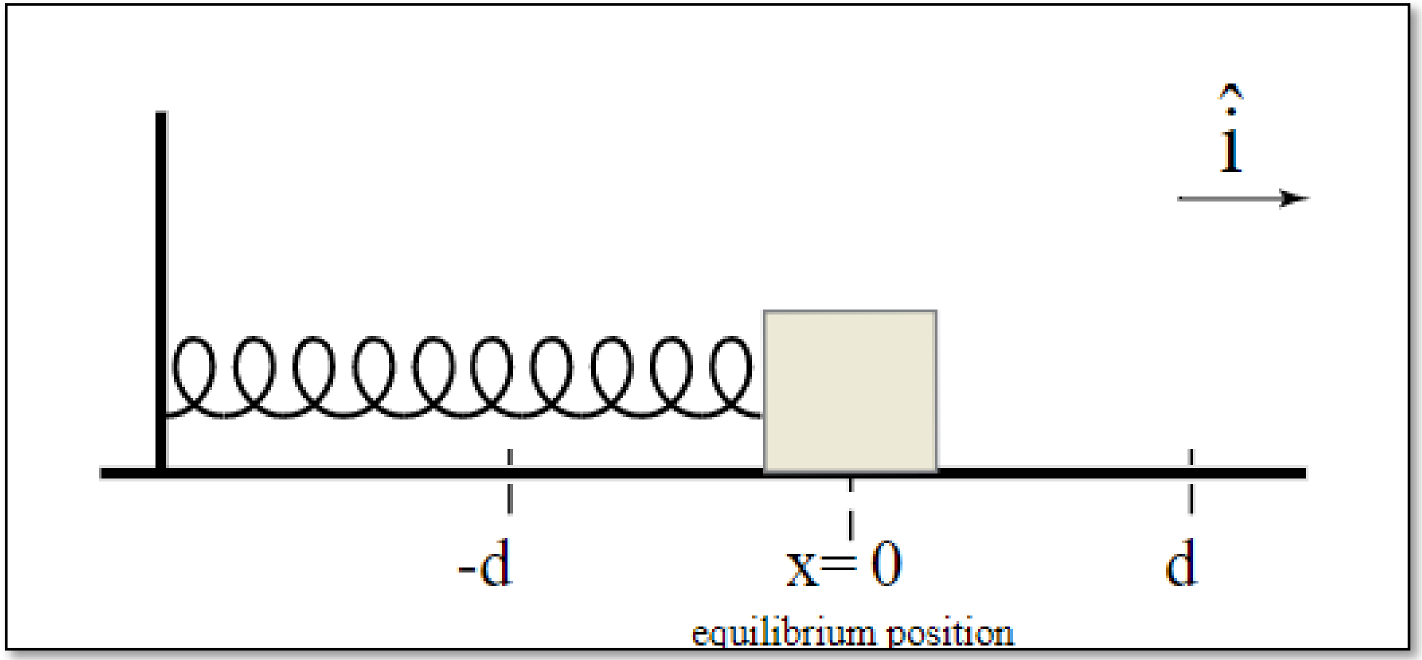
Work by a Non-Constant Force

$$W = \int_{A}^{B} \vec{F}.d\vec{s}$$



Solved Example

A block of mass m is attached to a horizontal spring of spring constant k. The force exerted by the spring on the box is $\vec{F}^s = F^s_x\,\hat{i} = -kx\,\hat{i}$. When the box is at $x = 0$ the spring is relaxed and $\vec{F}^s = 0$ (no spring force on the box).



What is the amount of work done when the box moves from (a) $x = 0$ *to* $x = d$, (b) $x = d$ *to* $x = 0$, (c) $x = d$ *to* $x = -d$

Ans:

$$W_{i\to f} = \int_i^f \vec{F}.\overrightarrow{ds}$$

$$(a)W_{0\to d} = -\int_0^d kxdx = -\frac{1}{2}kd^2$$

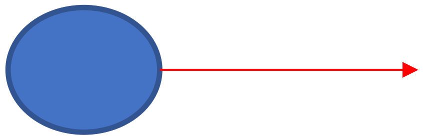
$$(b)W_{d\to 0} = -\int_d^0 kxdx = \frac{1}{2}kd^2$$

$$(c)W_{d\to -d} = -\int_d^{-d} kxdx = 0$$

Kinetic Energy

The kinetic energy of an object is the energy that it possesses because of its motion. The kinetic energy of a point mass m is given by

Moving at constant velocity



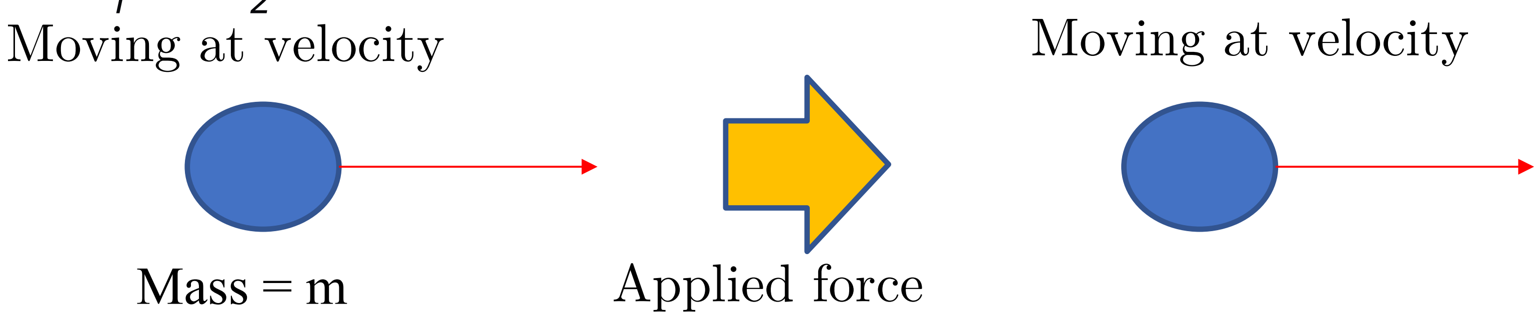
Mass = *m*

Kinetic energy K.E =) =

Unit = [J] = kg $(m/s)^2$

Work-Kinetic Energy Theorem

Suppose the speed changes from to while the particle undergoes displacement *S* = x_2-x_1 from point x_1 *to* x_2.



Work done by applied force on the mass m

,

Multiply m on both sides, $F = m$

$= K_f$ - $K_i = \Delta K$ (*Work-energy theorem*)

The work done by a net force on a particle equals the change in particle's kinetic energy

1. Calculate total kinetic frictional force of a moving block on a horizontal surface with mass 7Kg, when

A. 15 N B. 21 N C. 32 N D. None of the above

2. Two cars collide in a head on collision as shown in figure. They lock togethe
a. What is the speed and direction of the two cars after the collision?

QUIZ - 02

A. 1.15m/s, RIGHT

B. 2.23m/s, LEFT

C. 1.33 m/s, RIGHT

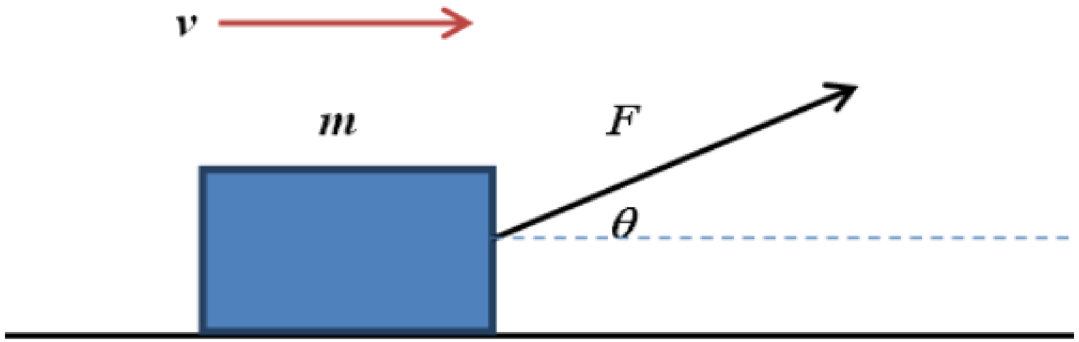
D. 4.34 m/s, LEFT

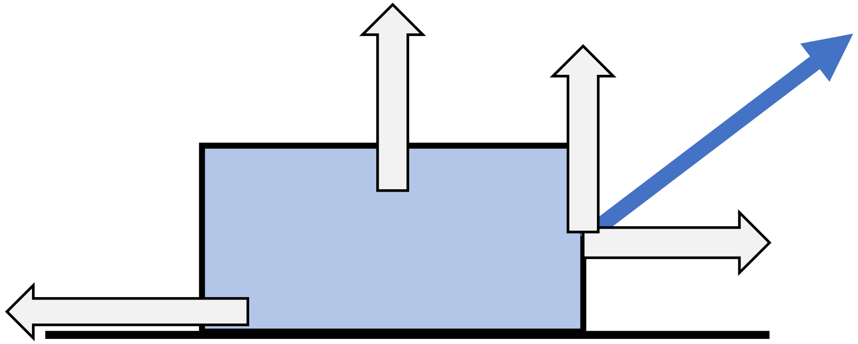
3. A 250g block moves on a rough surface (with).
How much work will be done by the frictional force to stop the block if the block was initially moving at a velocity of 40cm/sec.

A. +0.01J, B. -0.02J, C. -0.04J, D. +0.08J

Solved Example

A block of mass m is dragged along a rough horizontal surface by a constant force of magnitude F applied at an angle θ above the horizontal as shown. The speed of the block is constant and equals *v*. The block undergoes a displacement *d*.





(a) Find the work done on the block by external force F during this process.
(b) Find the work done by the normal force.
(c) Find the work done on the block by the force of friction during this process.
(d) Find total work done by all three forces.

Solution Help

$$\vec{F}_{Appl} = FCos\theta\hat{\imath} + FSin\theta\hat{\jmath},$$

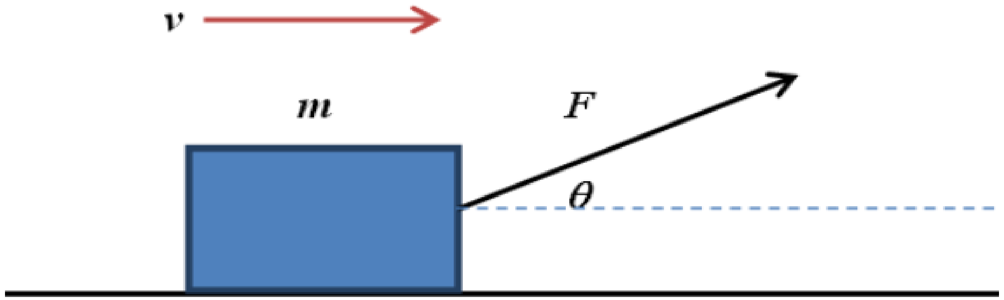
$$\vec{F}_{N.F.} = (mg - FSin\theta)(+\hat{\jmath}),$$

$$\vec{F}_{friction} = \mu_k(mg - FSin\theta)(-\hat{\imath})$$

$$\overrightarrow{\Delta x} = d(+\hat{\imath})$$

Solved Example

A block of mass m is dragged along a rough horizontal surface by a constant force of magnitude F applied at an angle θ above the horizontal as shown. The speed of the block is constant and equals *v*. The block undergoes a displacement *d*.



Solution Help

$$\vec{F}_{Appl} = FCos\theta\hat{\imath} + FSin\theta\hat{\jmath},$$
$$\vec{F}_{N.F.} = (mg - FSin\theta)(+\hat{\jmath}),$$
$$\vec{F}_{friction} = \mu_k(mg - FSin\theta)(-\hat{\imath})$$
$$\overrightarrow{\Delta x} = d(+\hat{\imath})$$

(a) Find the work done on the block by external force F during this process.
(b) Find the work done by the normal force.
(c) Find the work done on the block by the force of friction during this process.
(d) Find total work done by all three forces.

Ans: (a) $W_{Appl} = F.d.Cos\theta$,
(b) $W_{N.F.} = ZERO$
(c) $W_{friction} = -\mu_k d(mg - FSin\theta)$,
(d) $W_{Tot.} = ZERO \; as \; \Delta KE = 0$

POLL QUESTIONS

A 250g block moves on a rough surface (with).
How much work will be done by the frictional force to stop the block if the block was initially moving at a velocity of 40cm/sec.

A. +0.01J

B. -0.02J

C. -0.04J

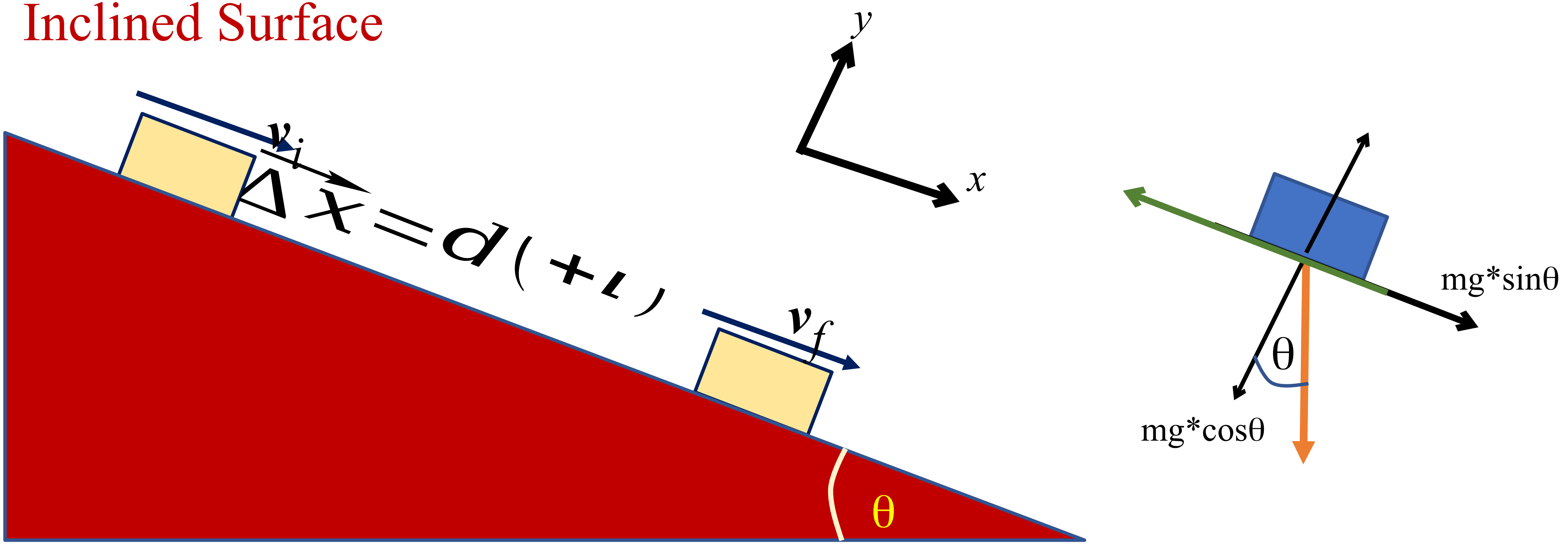
D. +0.08J

Ans:

W

Application of Work-Kinetic Energy Theorem

Inclined Surface



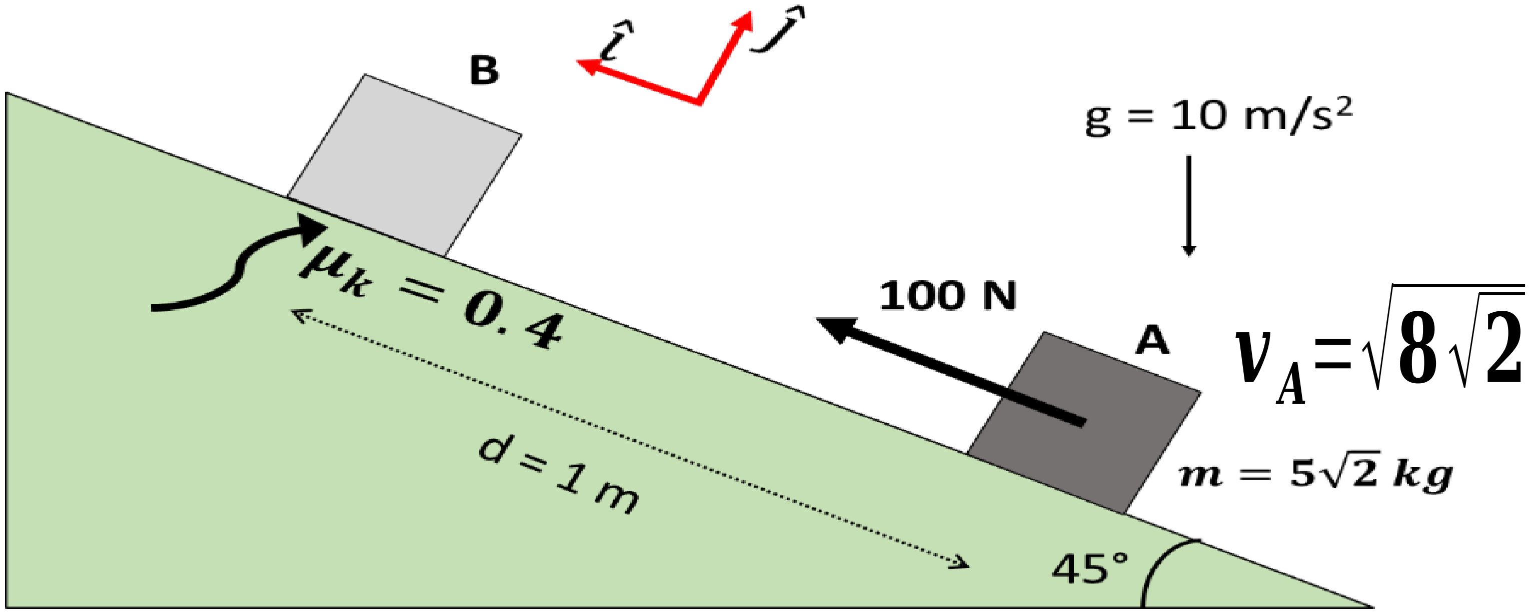
$+ 0$

Practice problems

Solved Example

A block of mass m= kg is dragged along a slope of rough surface (by a **constant force F** = 100 N as shown in the figure. The block moves a distance 1 m.

$\boldsymbol{v_B} = ?$



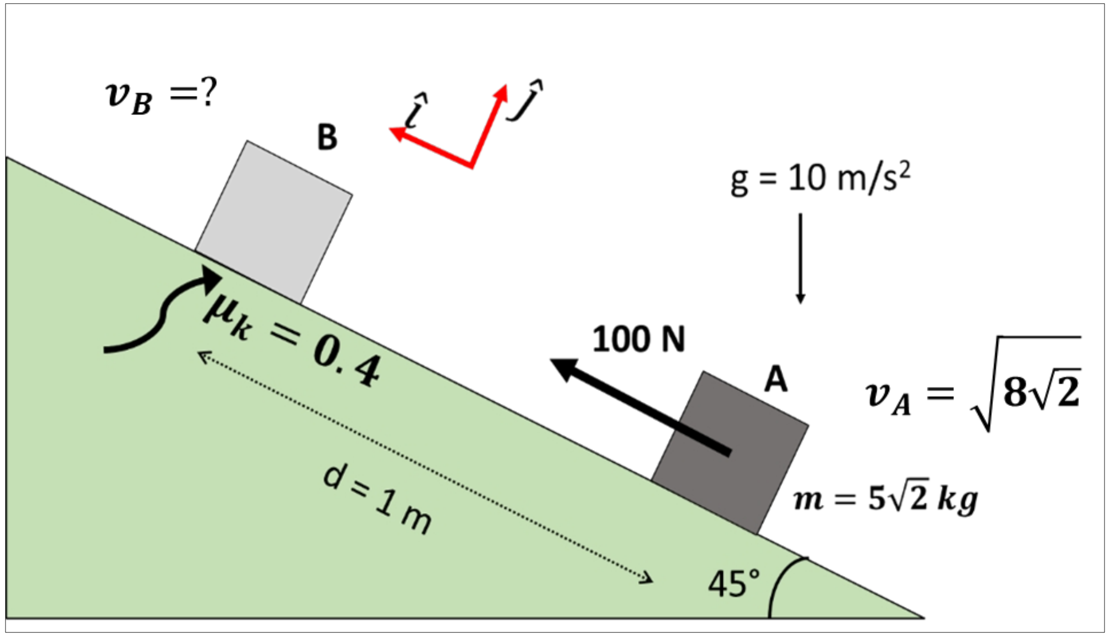
i. Draw the force diagram.

ii. Find the work done by

a) external force F, b) by normal force, N, c) friction force, *f* and d) gravity..

If the velocity at A is , then find the velocity at point B.

Solved Example



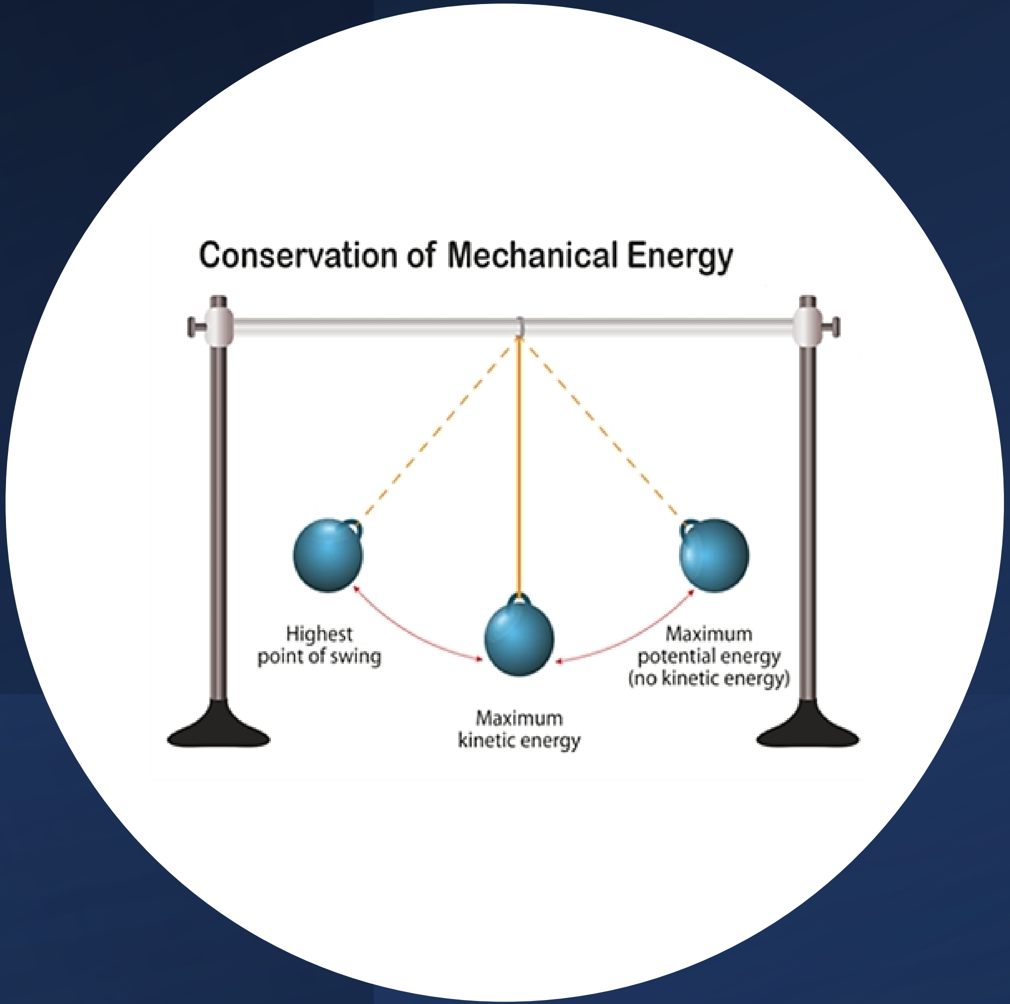
FORCES:

$= 20N$

$+$

Ans:

LECTURE-05



CONSERVATION OF MECHANICAL ENERGY

CONCEPT QUESTION

What is an example of mechanical energy

A. Electrical energy

B. Magnetic Energy

C. Thermal Energy

D. Potential Energy

CONCEPT QUESTION

Does violation of conservation of mechanical energy also violate overall energy conservation?

A. YES

B. NO

C. NOT POSSIBLE TO ANSWER

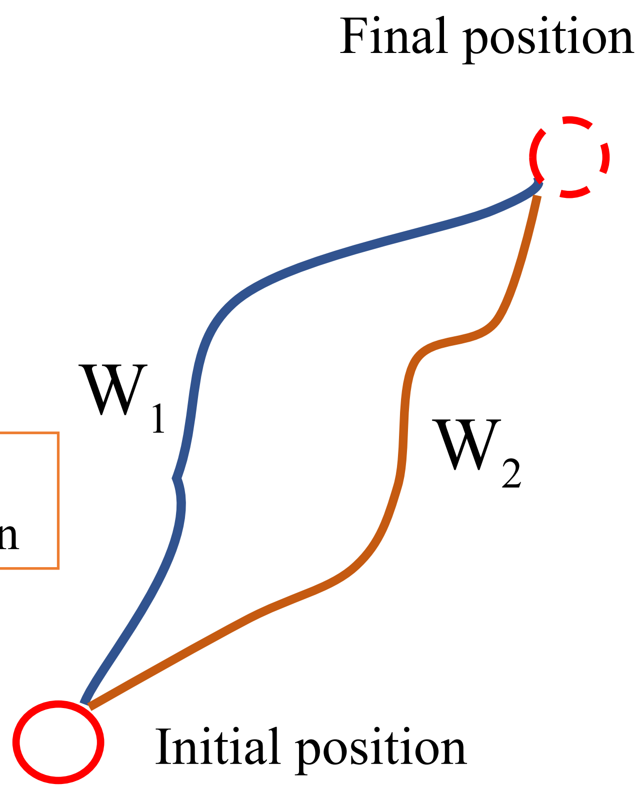
Conservative and non-conservative forces

Conservative force

A force is conservative if the work done by it on a particle that moves between two points is the same for all paths connecting these points.

$$W_1 = W_2 = \ldots\ldots = W_n$$

Example - Gravitational force, Spring force, and electric force



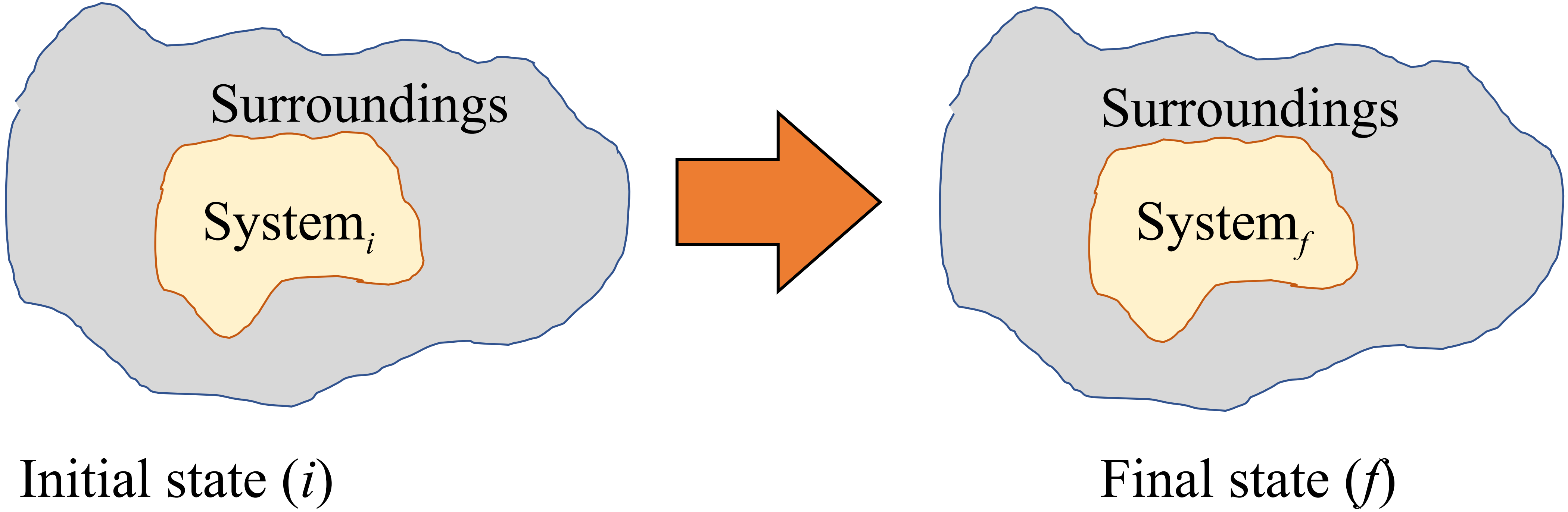
Non - conservative force

Whenever the work done by a force in moving an object from an initial point to a final point depends on the path, the force is called a non-conservative force.

Example - Friction force and air drag force

$$W_1 \neq W_2 \neq \ldots\ldots \neq W_n$$

Conservation of Energy



When a system and its surroundings undergo a transition from an initial state to a final state, the total change in energy is zero

$$\Delta E = \Delta E_{\text{system}} + \Delta E_{\text{surroundings}} = 0$$

Potential energy

The energy associated with the *position of a object* rather than its motion is known as potential energy.

Force and potential energy

Force from potential energy in one dimension

In three dimension $F_x = -\frac{\partial u}{\partial x}$ $F_y = -\frac{\partial u}{\partial y}$ $F_z = -\frac{\partial u}{\partial z}$

$$\vec{F} = -\left(\frac{\partial u}{\partial x}\hat{i} + \frac{\partial u}{\partial y}\hat{j} + \frac{\partial u}{\partial z}\hat{k}\right)$$

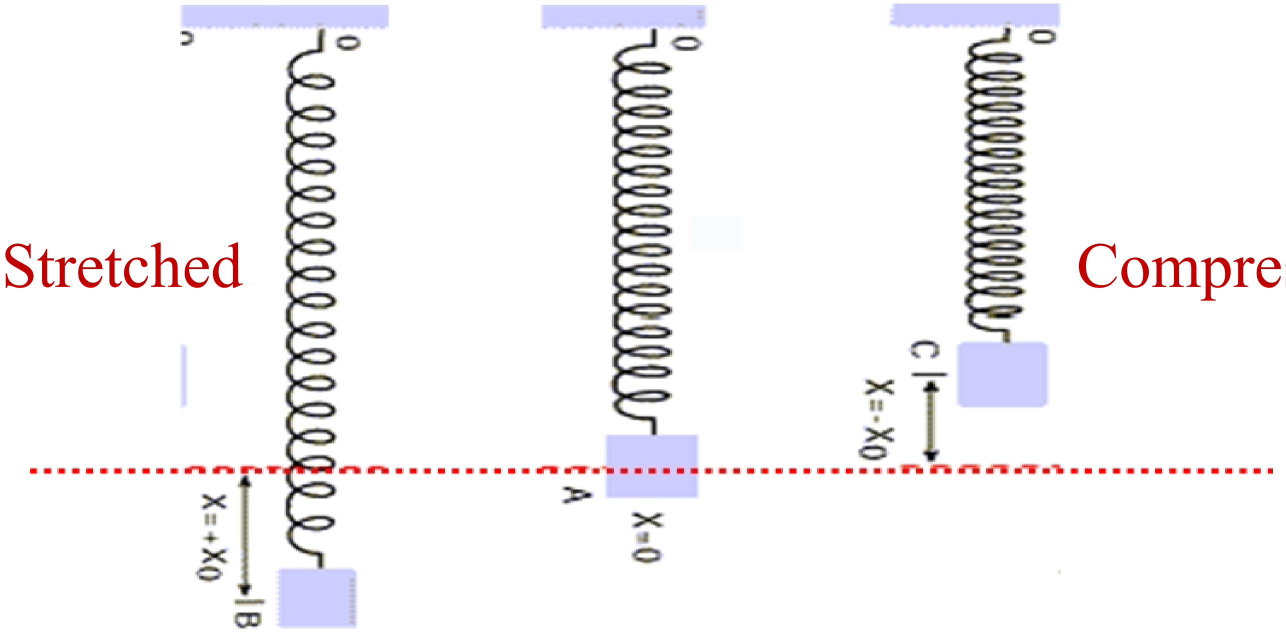
Potential energy due to Springs

Restoring force, F

$$\vec{F} = -\frac{dU}{dx} = -kx\,\hat{\imath}$$

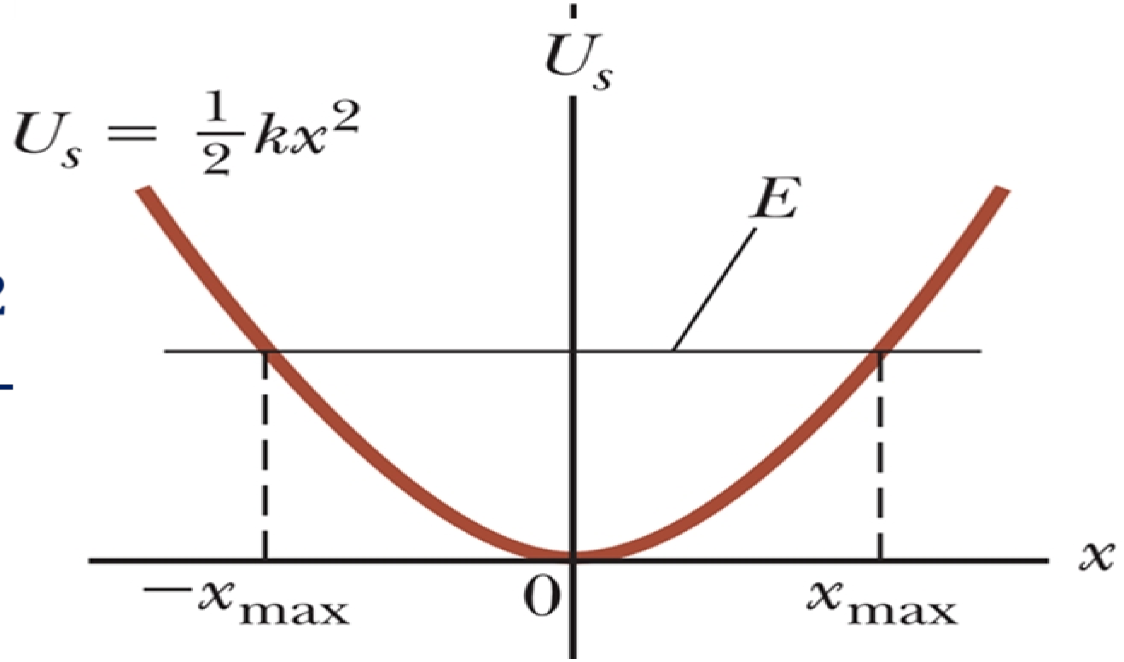
HOOKE'S LAW

Stretched

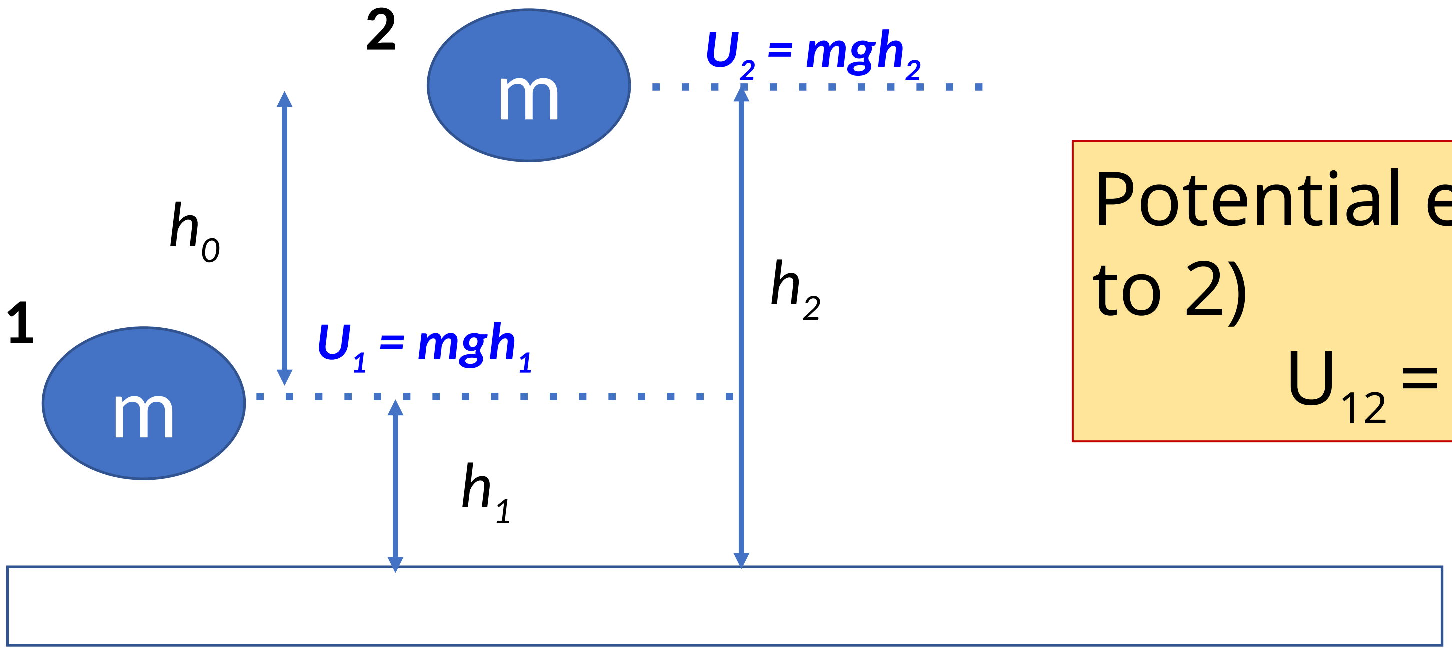


Compressed

$$\Delta U = -W = -\int \vec{F}\cdot\overrightarrow{ds} = \frac{kx^2}{2}$$



Gravitational potential energy

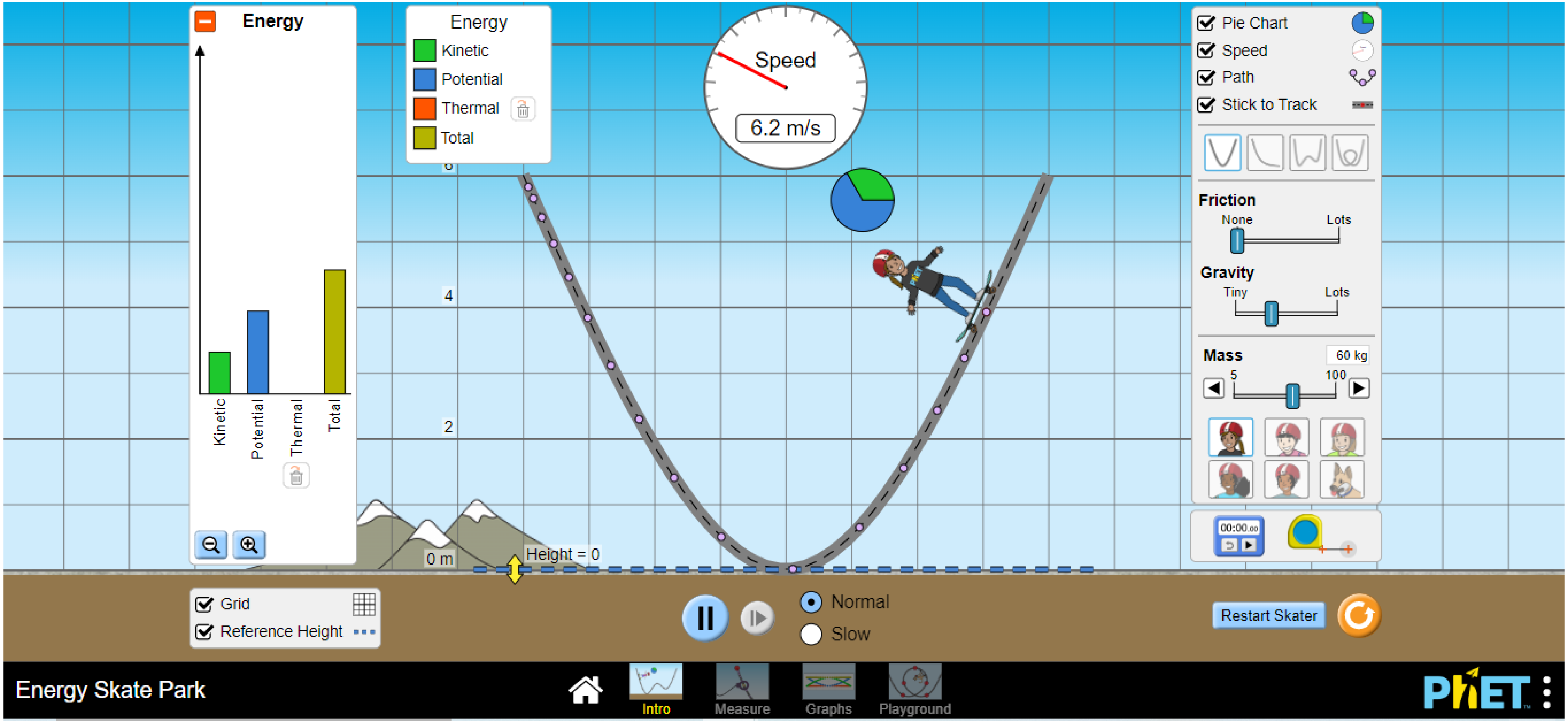


Potential energy change (from 1 to 2)

$$U_{12} = mg(h_2 - h_1) = mgh_0$$

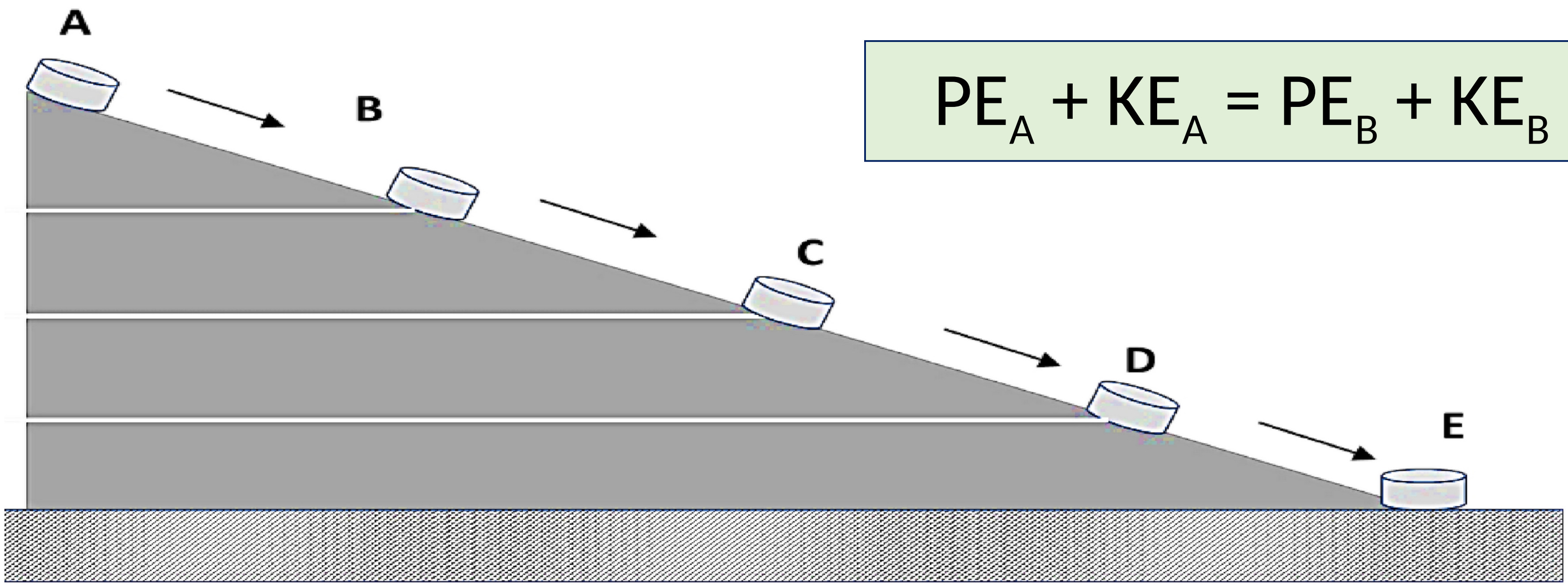
Potential energy change wrt a reference at 1: $U_0 = mgh_0$

INTERACTIVE PRESENTATION

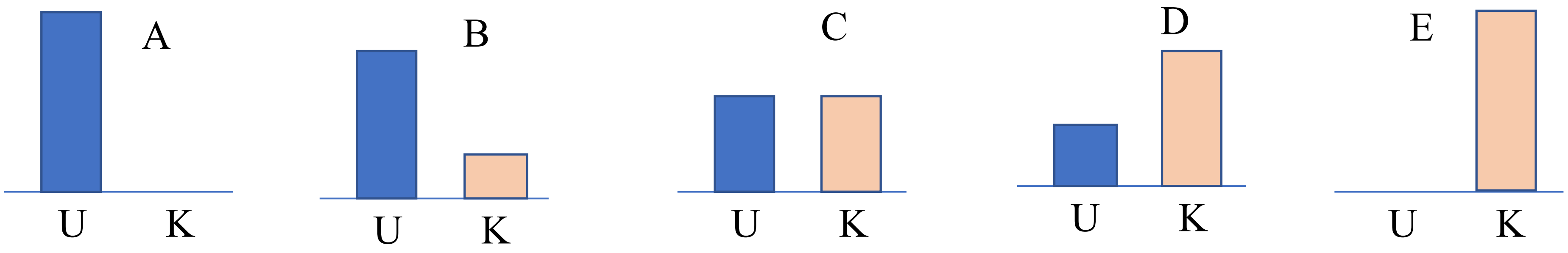


https://phet.colorado.edu/sims/html/energy-skate-park/latest/energy-skate-park_en.html

Conservation of Mechanical Energy
Slipping Object on Frictionless inclined surface



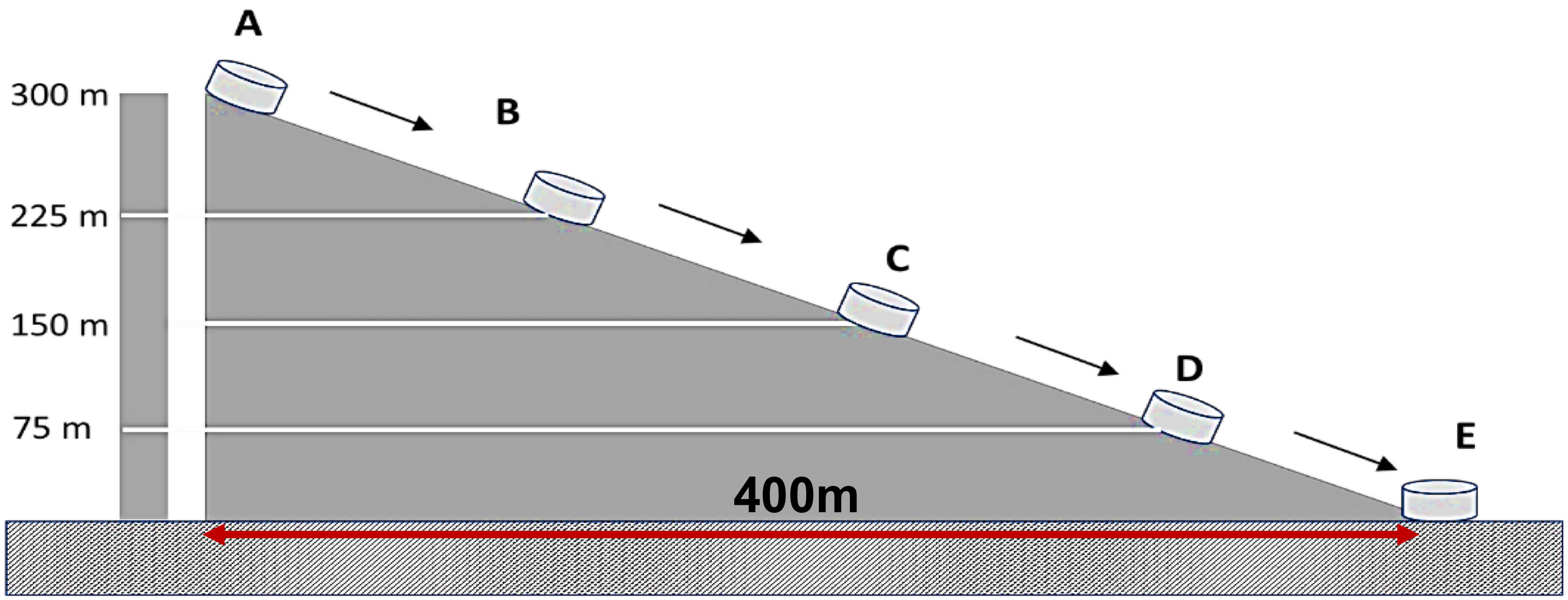
$$PE_A + KE_A = PE_B + KE_B$$



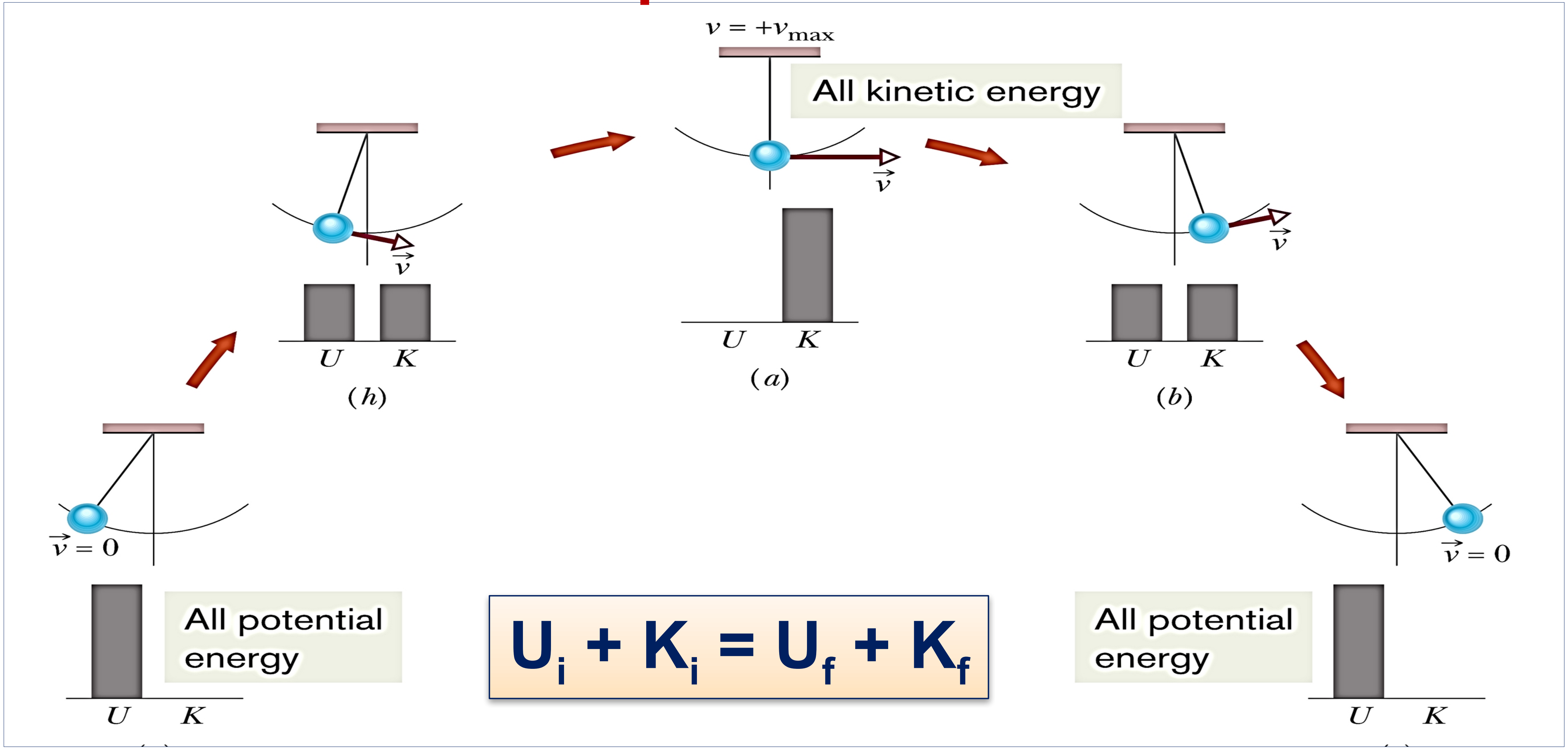
POLL QUESTION

A body is slipping on a frictionless surface.

What is the velocity at that point C & E respectively?



Conservation of Mechanical Energy
Simple Pendulum



POLL QUESTION

A simple pendulum (bob mass, m = 0.2 kg) has a velocity of v = 20 m/s at the lowest position. Ignore air friction

(a)What is the height the pendulum reaches at maximum position B w.r.t the lowest position?

A. 10m

B. 20m

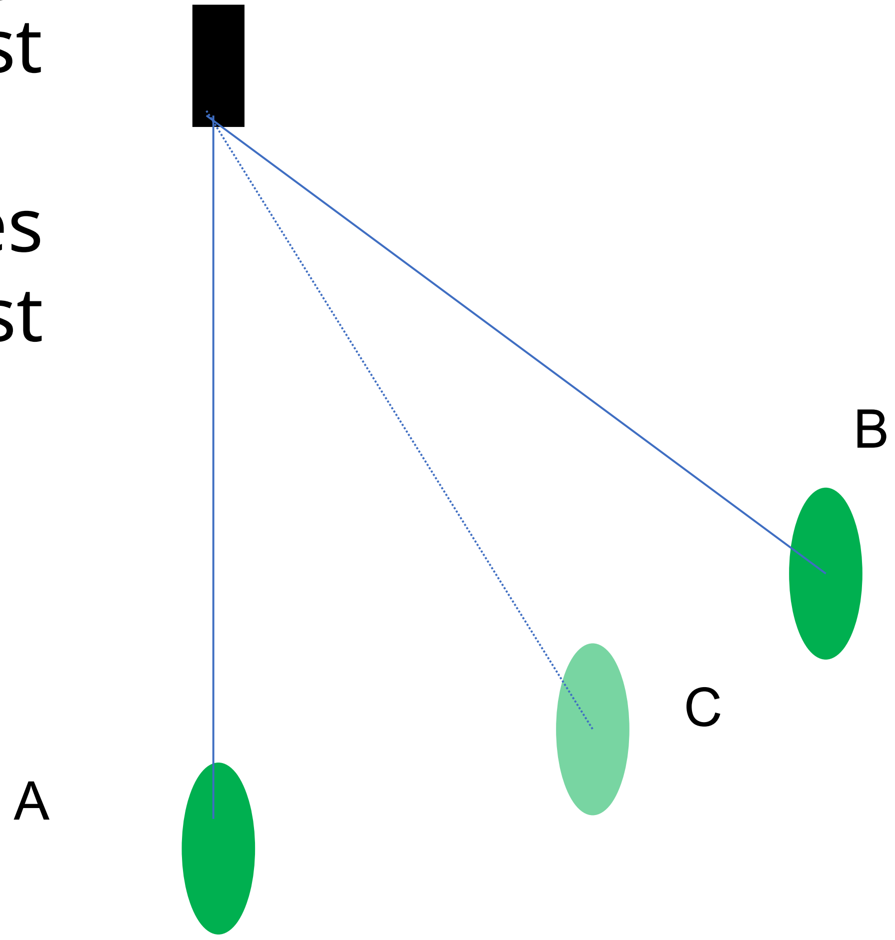
C. 30m

D. 40m

$K_1+U_1=K_2+U_2$

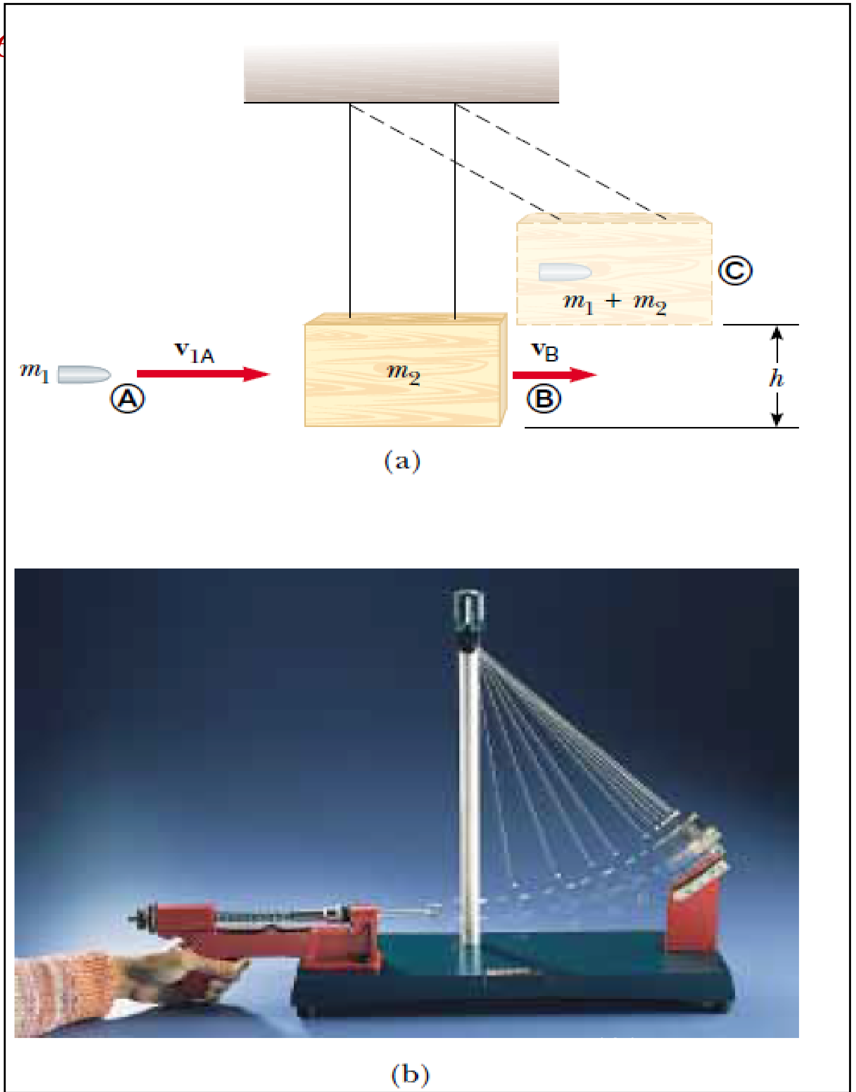
$=0,$

m



Assume g=10m/s²

Problem: The ballistic pendulum given in the figure is an apparatus used to measure the speed of fast moving projectile such as bullet. A bullet of mass m_1 is fired into a large block of wood of mass m_2 suspended from some light wires. The bullet embeds in the block and entire system swings through a height h. *How can we determine the speed of the bullet from a measure*



(a)

(b)

……(1)

Total kinetic energy after the collision.

LECTURE 06

Mechanical Properties of Solids

CONCEPT QUESTION

What are the units of mechanical stress and strain?

A. Newton and meter

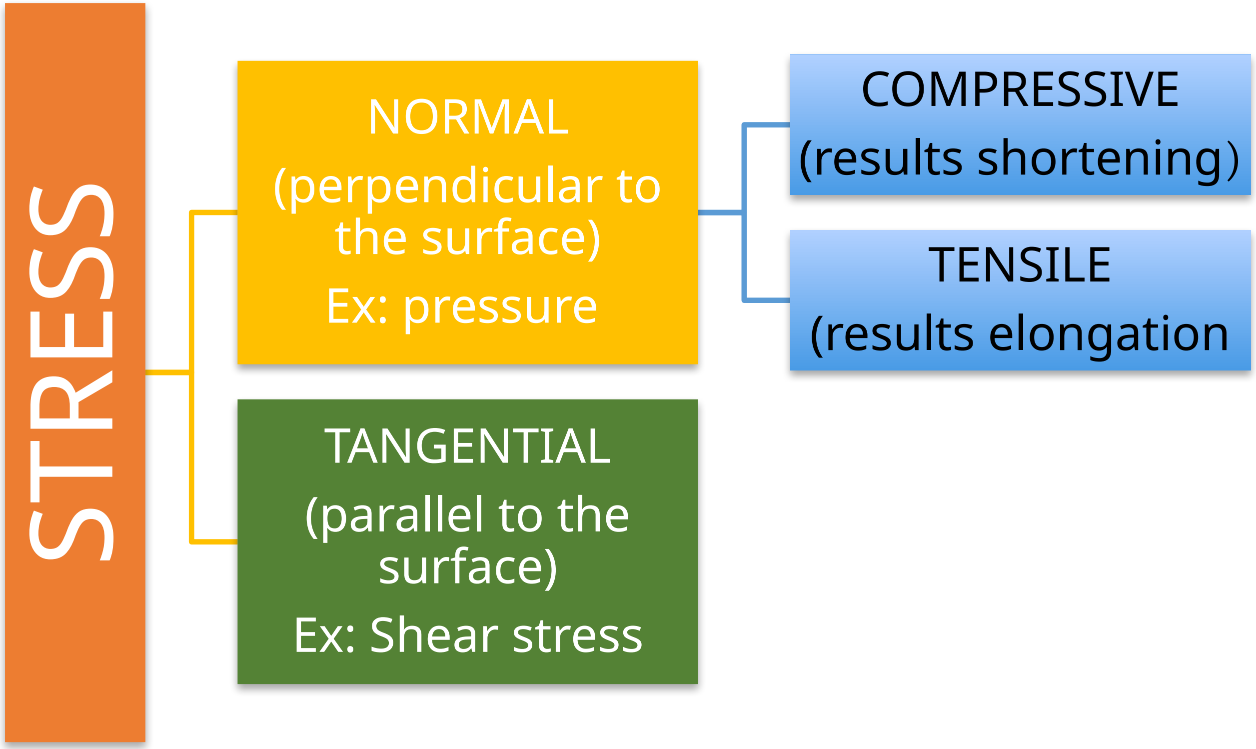
B. Pascal and meter

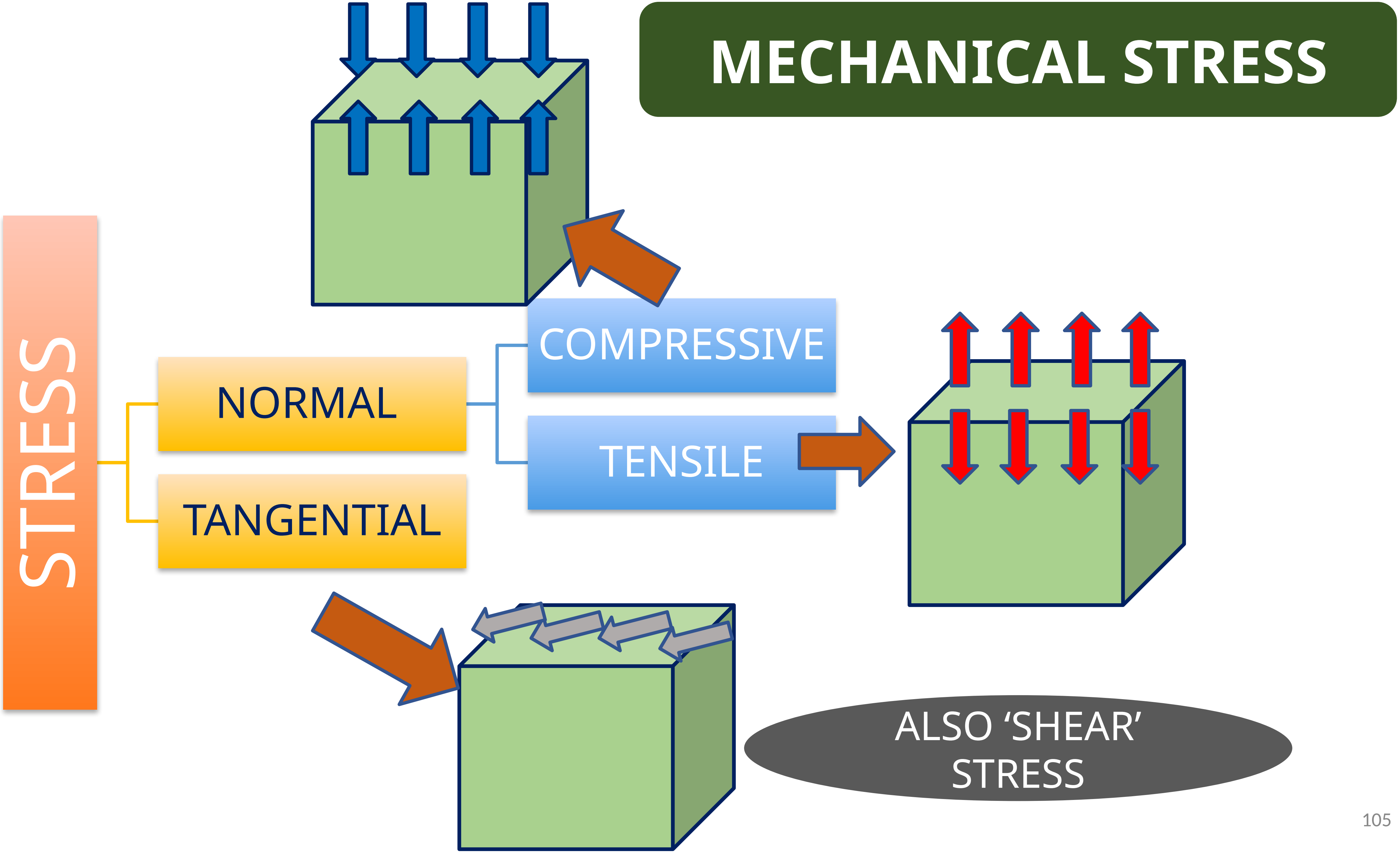
C. Pascal and no unit

D. Newton and no unit

MECHANICAL STRESS

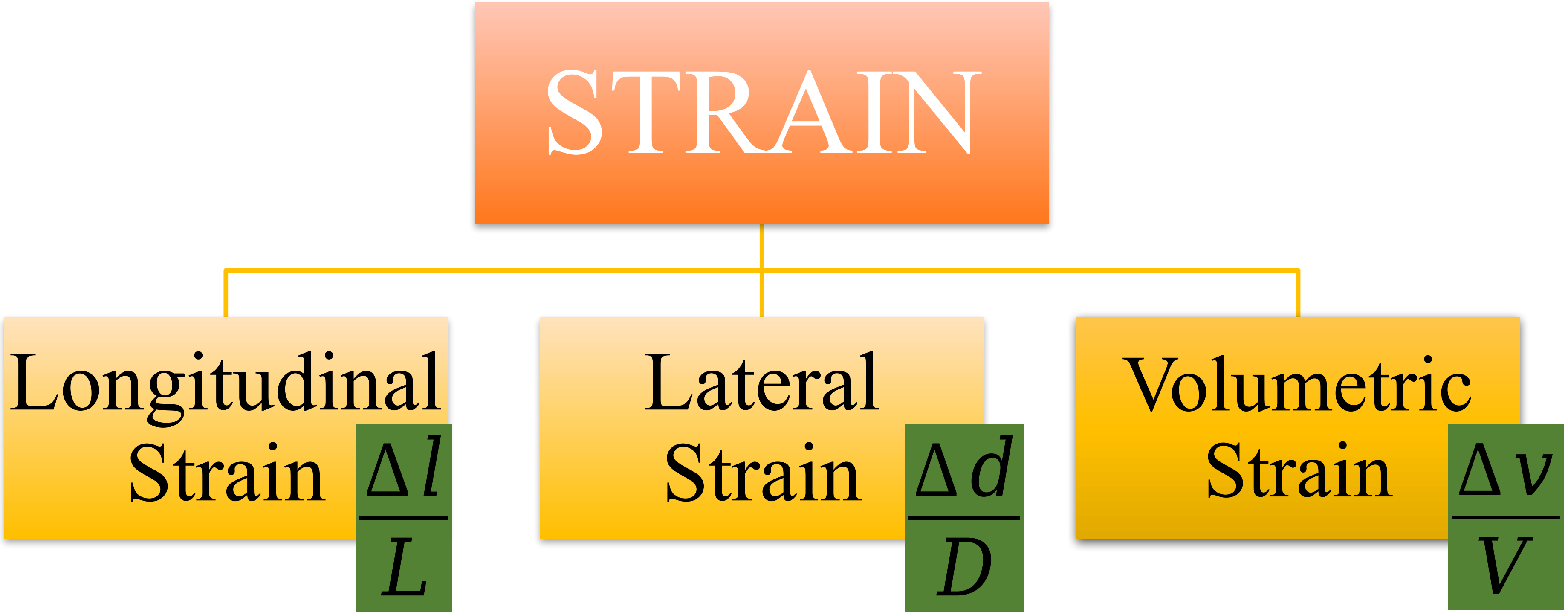
- The restoring force (F) per unit area (A) is called stress.
- The unit of stress in S.I system is N/m^2 and in C.G.S-dyne/cm^2.
- The dimension of stress = $[M^1L^{-1}T^{-2}]$.
- Stress = F/A



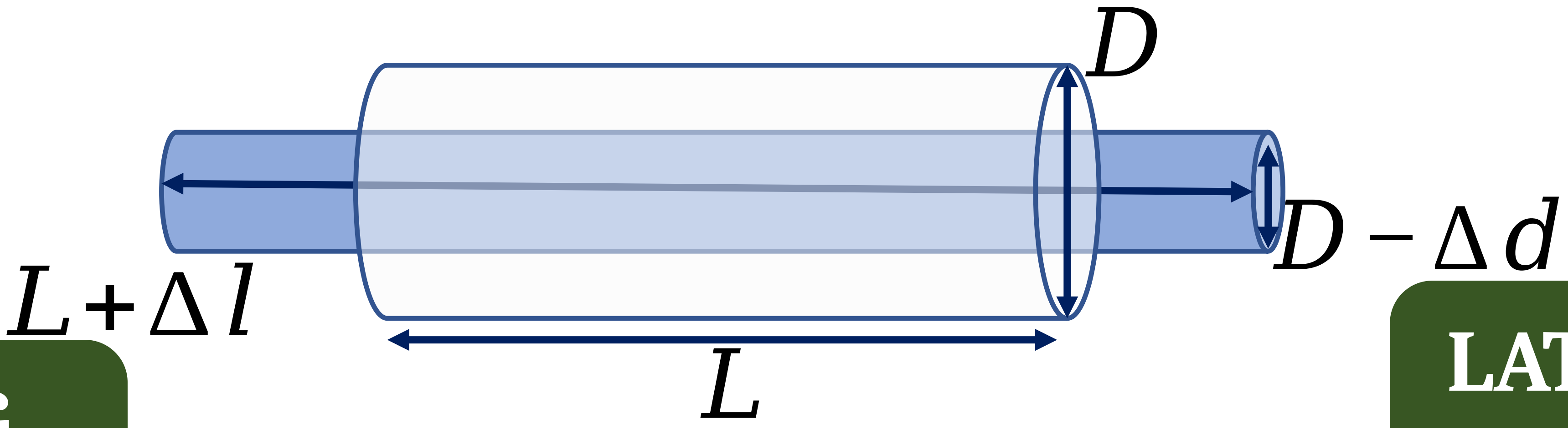

MECHANICAL STRESS
STRESS
NORMAL
TANGENTIAL
COMPRESSIVE
TENSILE
ALSO 'SHEAR' STRESS

MECHANICAL STRAIN

- The strain is the relative change in configuration due to the application of deforming forces.
- It has no unit or dimensions.



MECHANICAL STRAIN



LONG. STRAIN

$$\frac{\Delta l}{L}$$

Longitudinal strain is change in the length to the original length of an object

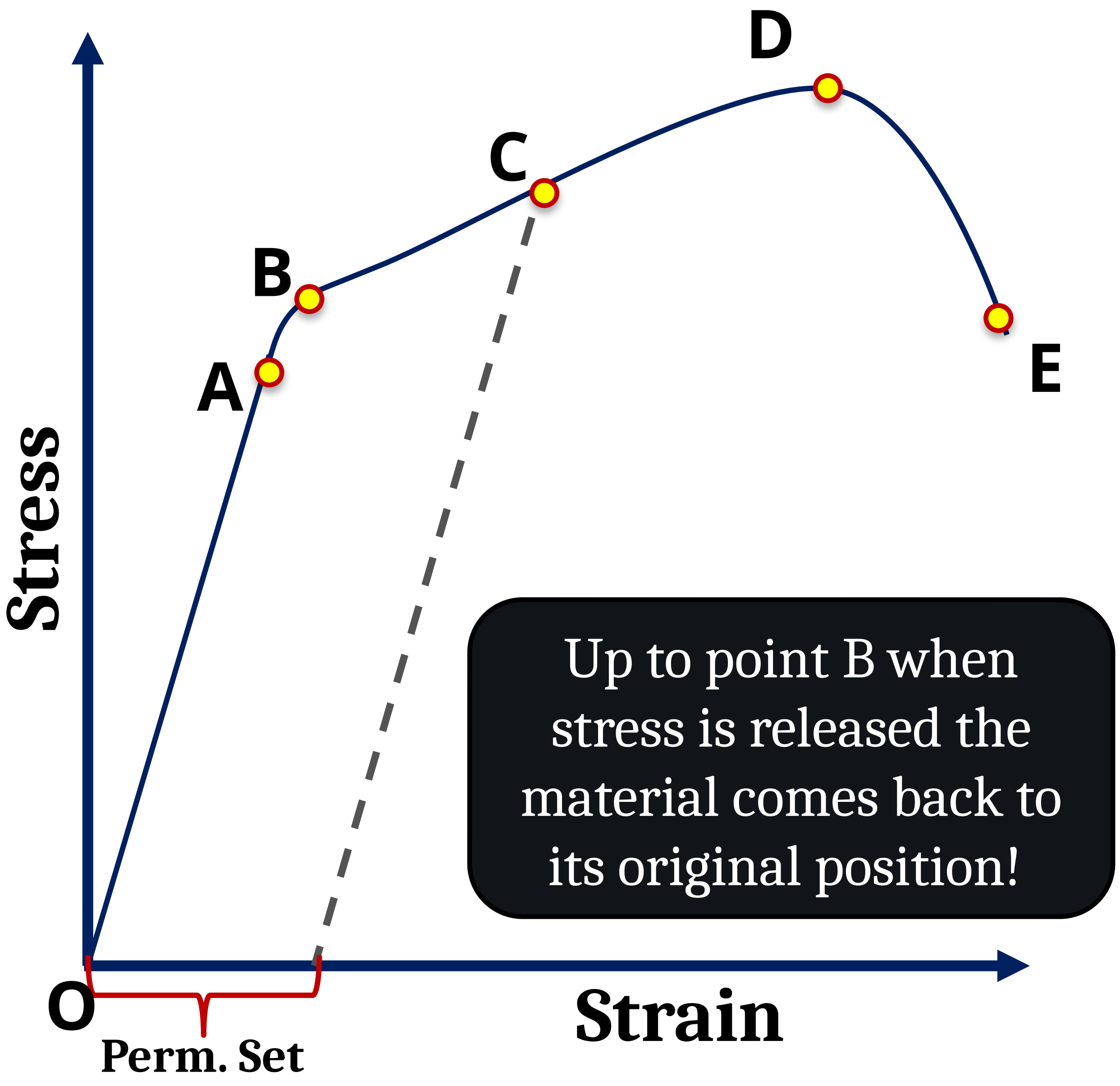
LATERAL STRAIN

$$-\frac{\Delta d}{D}$$

HOOKE'S LAW

HOOKE'S LAW

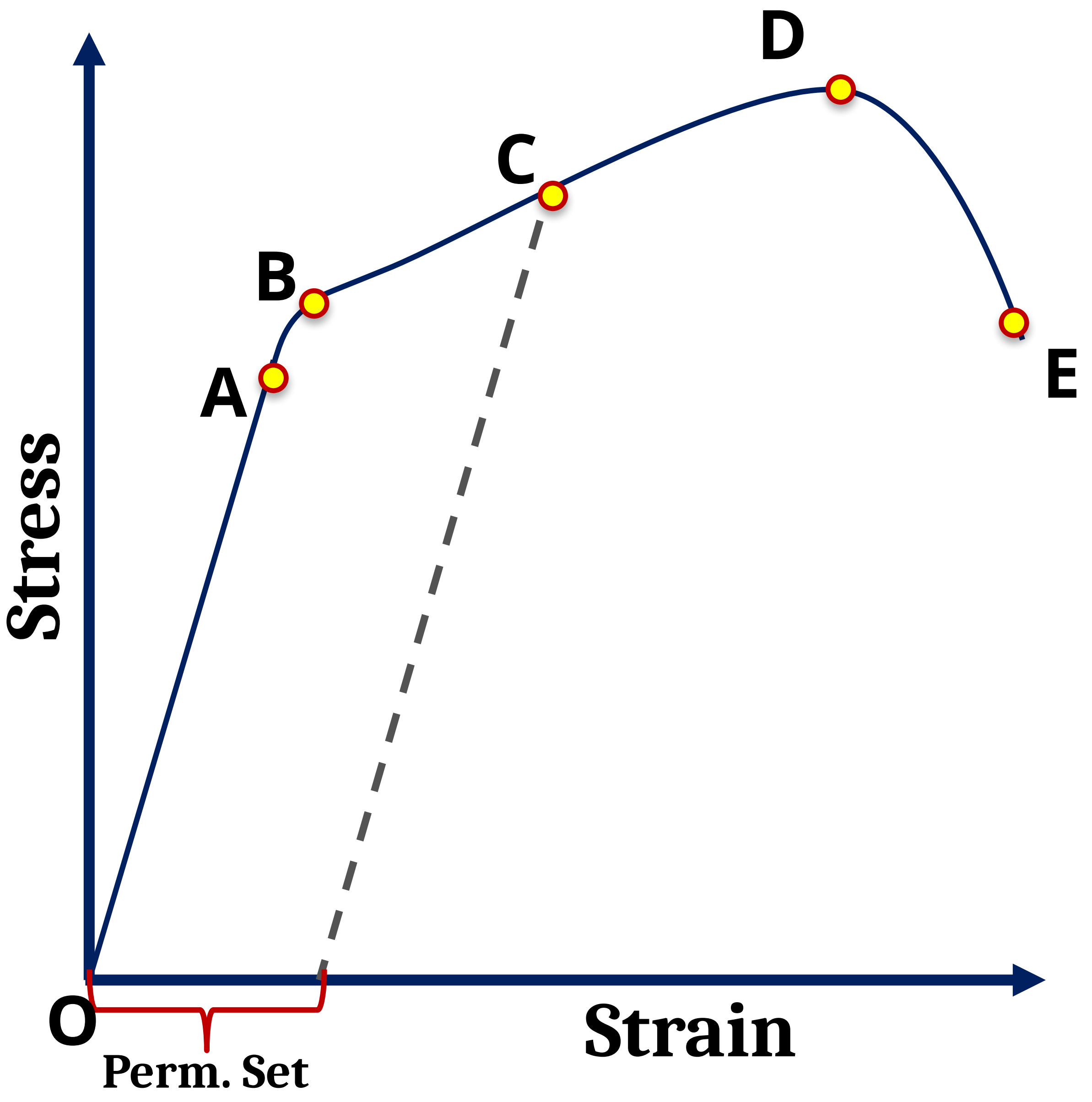
k is called elastic moduli



HOOKE'S LAW

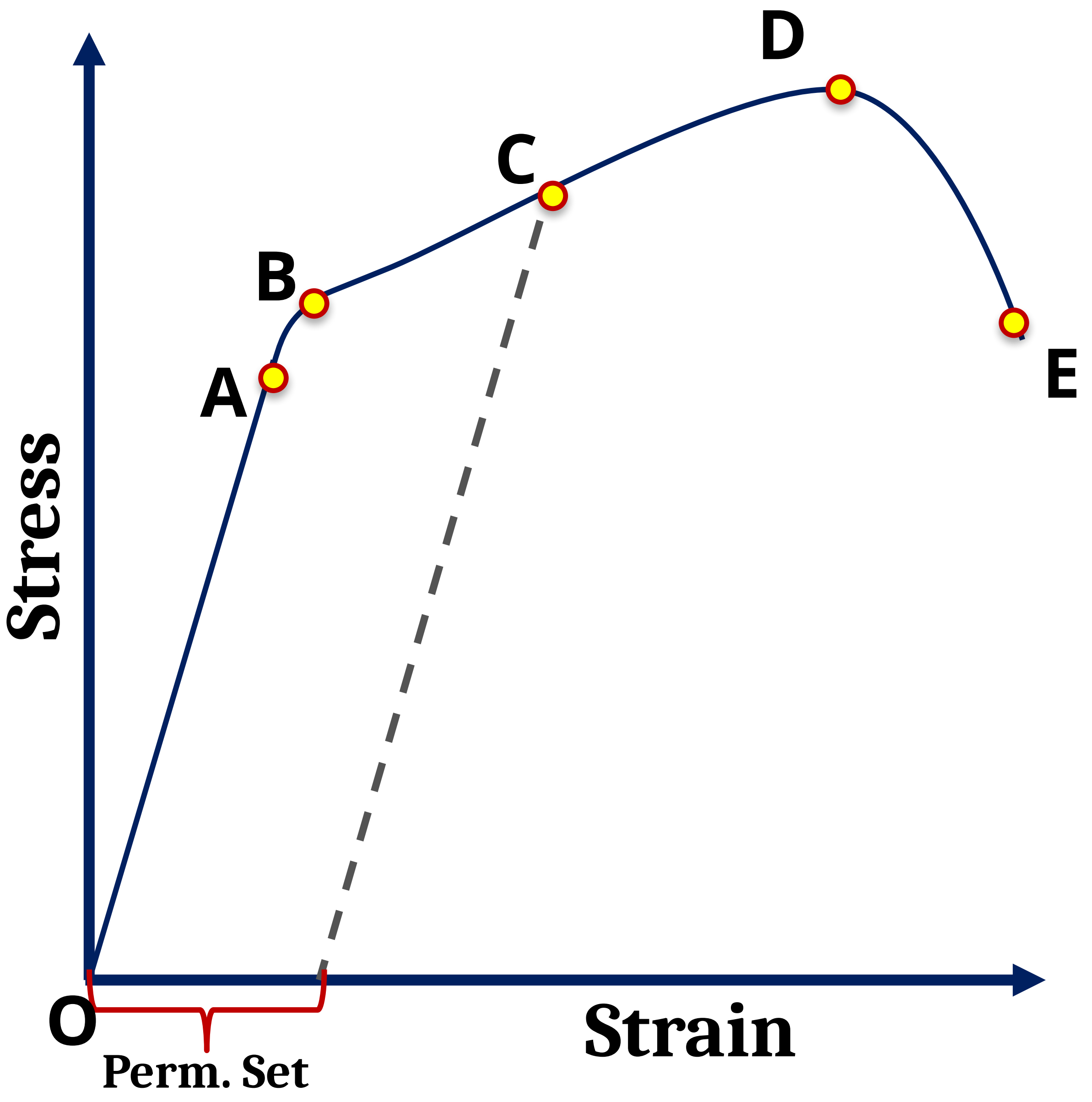
In the region BC,

- ✓ *the body does not regain its original dimension.*
- ✓ *Even with zero stress the strain is not zero.*
- ✓ *The material is said to have a* ***permanent set****.*
- ✓ *The deformation is said to be* ***plastic deformation.***

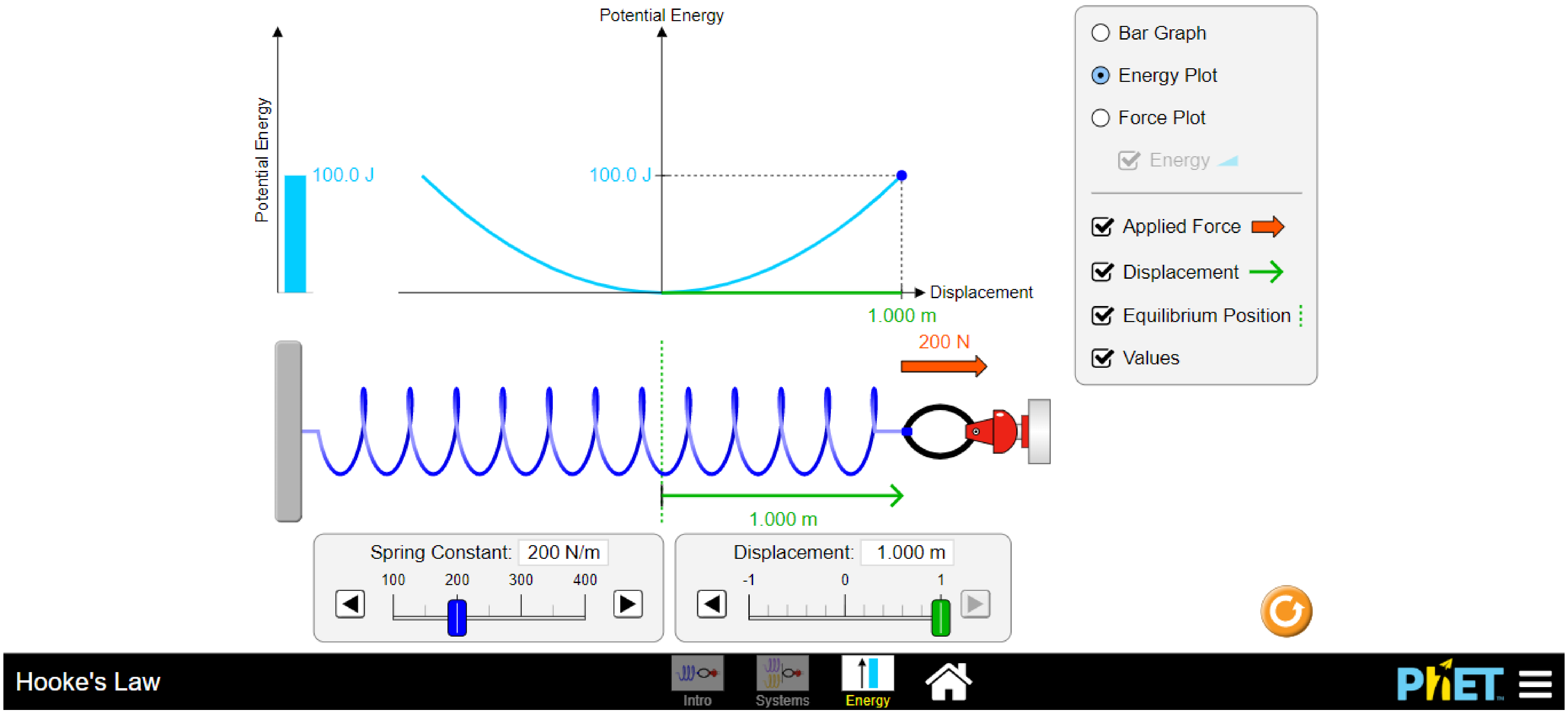


HOOKE'S LAW

- *Corresponding stress at D is called* ***ultimate tensile strength***
- ***Fracture happens at E***
- (hard but liable to break easily)
- able to be drawn out into a thin wire)



INTERACTIVE PRESENTATION



https://phet.colorado.edu/sims/html/hookes-law/latest/hookes-law_en.html

Elastic Moduli (k)

Elastic Moduli

- YOUNG'S MODULUS
- RIGIDITY MODULUS
- BULK MODULUS

UNIT IS N/m^2 => Unit of Stress

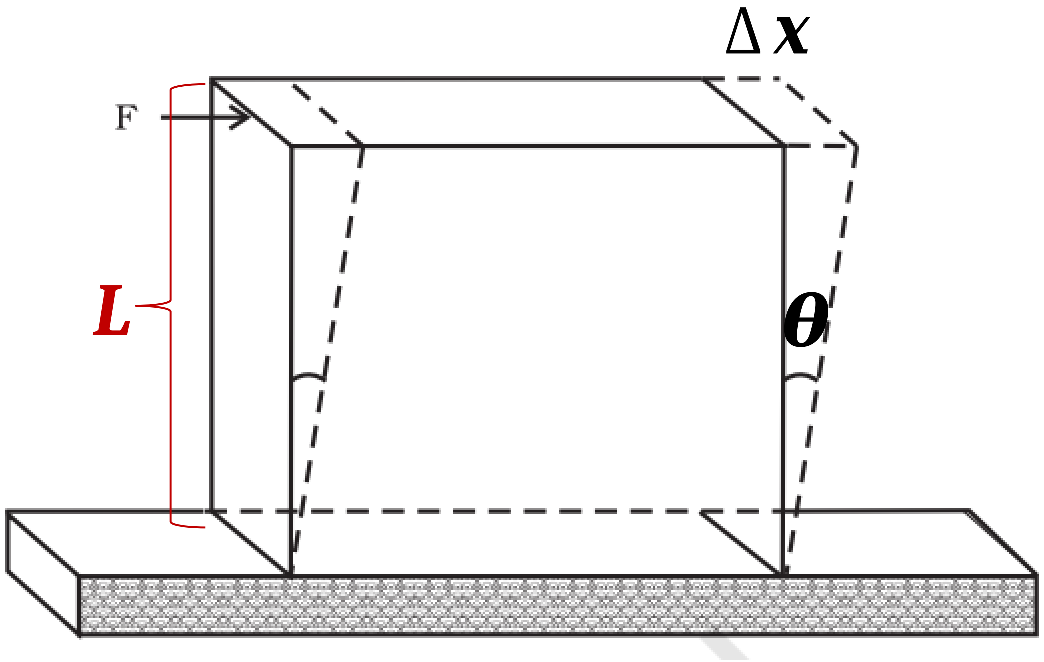
All elastic moduli
UNIT IS N/m^2 => Unit of Stress

Elastic Moduli (k)

Elastic Moduli

- YOUNG'S MODULUS
- RIGIDITY MODULUS
- BULK MODULUS

$$\frac{Shear\ Stress\,(\sigma_s)}{shear\ strain\,(\varepsilon_s)} \Rightarrow G = \frac{\frac{F}{A}}{\frac{\Delta x}{L}} = \frac{\frac{F}{A}}{\theta} = \frac{F}{(A \times \theta)}$$



Elastic Moduli (k)

Elastic Moduli

- YOUNG'S MODULUS
- RIGIDITY MODULUS
- BULK MODULUS

- ✓ when a body is submerged in a fluid, it undergoes a hydraulic Stress.
- ✓ This leads to the decrease in the volume of the body thus producing volume strain.
- ✓ Their ratio is called Bulk Modulus.

$$\frac{Hydraulic\,Stress\,(p)}{hydraulic\,strain\,(v_s)} \Rightarrow B = \frac{p}{\frac{\Delta V}{V}} = \frac{p \times V}{\Delta V}$$

$$Compressibility\,(\kappa) = \frac{1}{B} = \frac{\Delta V}{p \times V}$$

SOLVED EXAMPLE

A structural steel rod has a radius of 10 mm and a length of 1.0 m. A 100 kN force stretches it along its length. If the corresponding strain is 16% then

Calculate (a) stress, (b) Young's Modulus and (c) elongation on the rod.

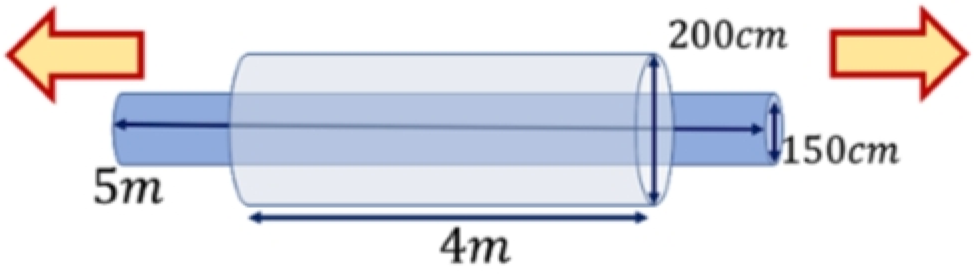


Figure above shows change of dimension of an elastic cylinder under of the influence of ***100N*** stretching force.

a) Calculate initial and final mechanical stress.

b) Longitudinal and Lateral Strain.

c) Poisson's Ratio

Initial mechanical stress =

Final mechanical stress =

Longitudinal strain = 0.25

Poisson's ratio= 1

Lateral strain = 0.25