FIC 102 : Engineering Physics

Instructor:
Dr. Amit Chakraborty (Physics)
Email: amit.c@srmap.edu.in

Class timing & Weekly meeting time

Class timing:

Monday : 12.30 PM– 1.30 PM

Friday : 10 AM– 11 AM

(Room number: S-513)

Meeting time:

Tuesday : 2 – 4 PM

(SR Building, Level 5, Cabin 13)

CONTENT

MARK DISTRIBUTION

(A) Continuous Evaluation		Assessment tool	Conducting Marks	Converting Marks	Final Conversion
Theory		Mid-term	25	20	**30**
		CLA-I	15	15	
		CLA-II	15	15	
Practical		Lab performance	20	20	**20**
		Model exam	50	20	
		Observation note	10	10	
				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 Practical record Viva	100	**20**
		Total	**50**

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

Course Objectives / Course Learning Rationales (CLRs)

Objective 1: To understand fundamental concepts of classical mechanics and elastic properties of solids.

Objective 2: To learn fundamentals of Electromagnetism and Maxwell's equation as the foundation of Maxwell's Equation.

Objective 3: To understand laws of Geometrical and Wave Optics and waves properties of light.

Objective 4: To familiarize about particle properties of waves and related fundamentals.

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

Recommended Resources

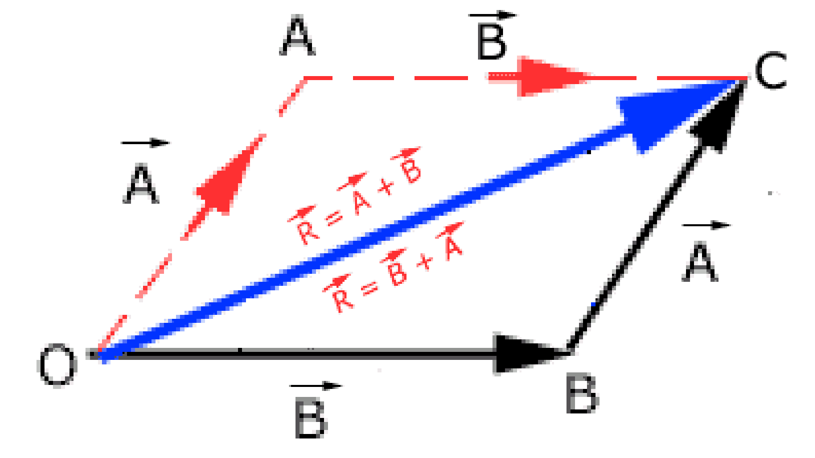
1. **University Physics with Modern Physics with Mastering Physics - D Young, Roger A Freedman And Lewis Ford, XII Edition (2018), Publisher – PEARSON**
2. **Physics for Scientist and Engineers - Raymond A. Serway, John W. Jewett, XIX Edition (2017), Publisher - Cengage India Private Limited**
3. Concept 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

LECTURE-01

Introduction to Vector and Coordinate systems



CONCEPT QUESTION

Find out the only vector from the following list

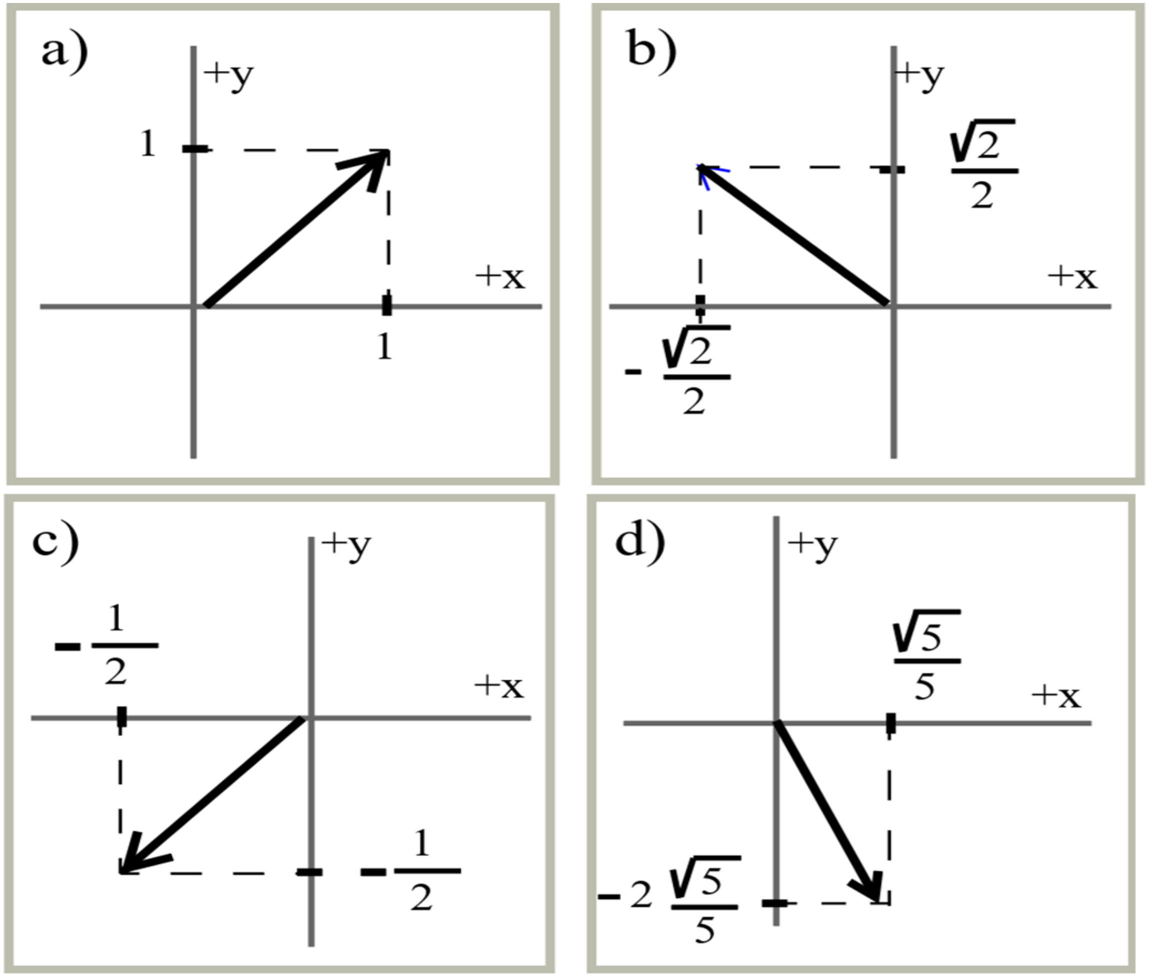
A. Temperature

B. Time

C. Velocity

D. Speed

CONCEPT QUESTION



Which one of these are unit vector(s)?

A. Option (a) ✓

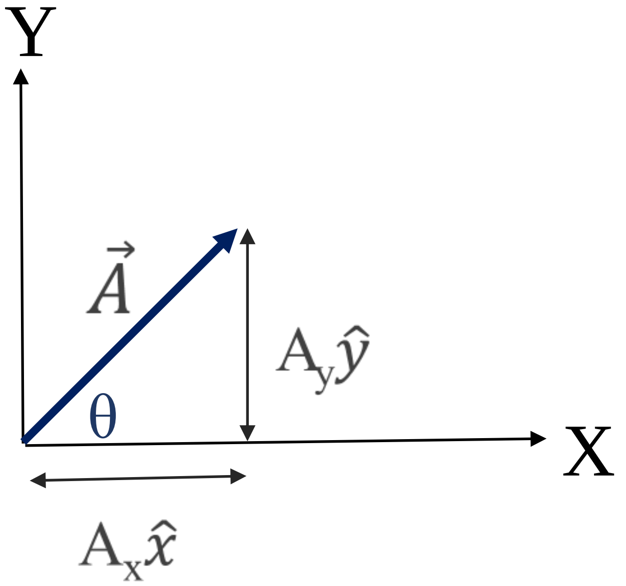
B. Option (b) ✓

C. Option (c)

D. Option (d) ✓

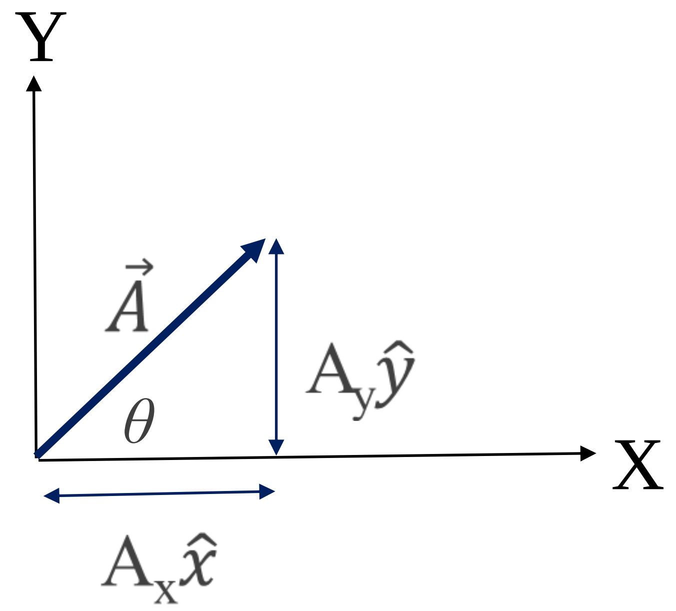
Vector Analysis

- The physical quantities that have magnitude, but no direction are called scalars.
- EXAMPLES: mass, charge, density, temperature etc.
- In contrast 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, $\vec{A}$: For a vector $\vec{A} = A_x\hat{x} + A_y\hat{y}$
- A_x and A_y are the components of the vector.
- $\hat{x}$ and $\hat{y}$ are the unit vectrors along X and Y axes respectively.



Vector Analysis

- The magnitude of the vector is:
- $|\vec{A}| = A = \sqrt{A_x^2 + A_y^2}$
- From the diagram:
- $A_x = A\cos\theta$, $A_y = A\sin\theta$ So, $\tan\theta = \frac{A_y}{A_x}$ or $\theta = \tan^{-1}\frac{A_y}{A_x}$
- Unit vector $\hat{A} = \frac{\vec{A}}{A} = \frac{A_x\hat{x} + A_y\hat{y}}{\sqrt{A_x^2 + A_y^2}}$



- In 3 dimensions, a vector is represented by
- $\vec{A} = A_x\hat{x} + A_y\hat{y} + A_z\hat{z}$
- Here A_x , A_y and A_z are the components of the vector.
- $\hat{x}$, $\hat{y}$ and $\hat{z}$ are the unit vectors along X, Y and Z axes, respectively.

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

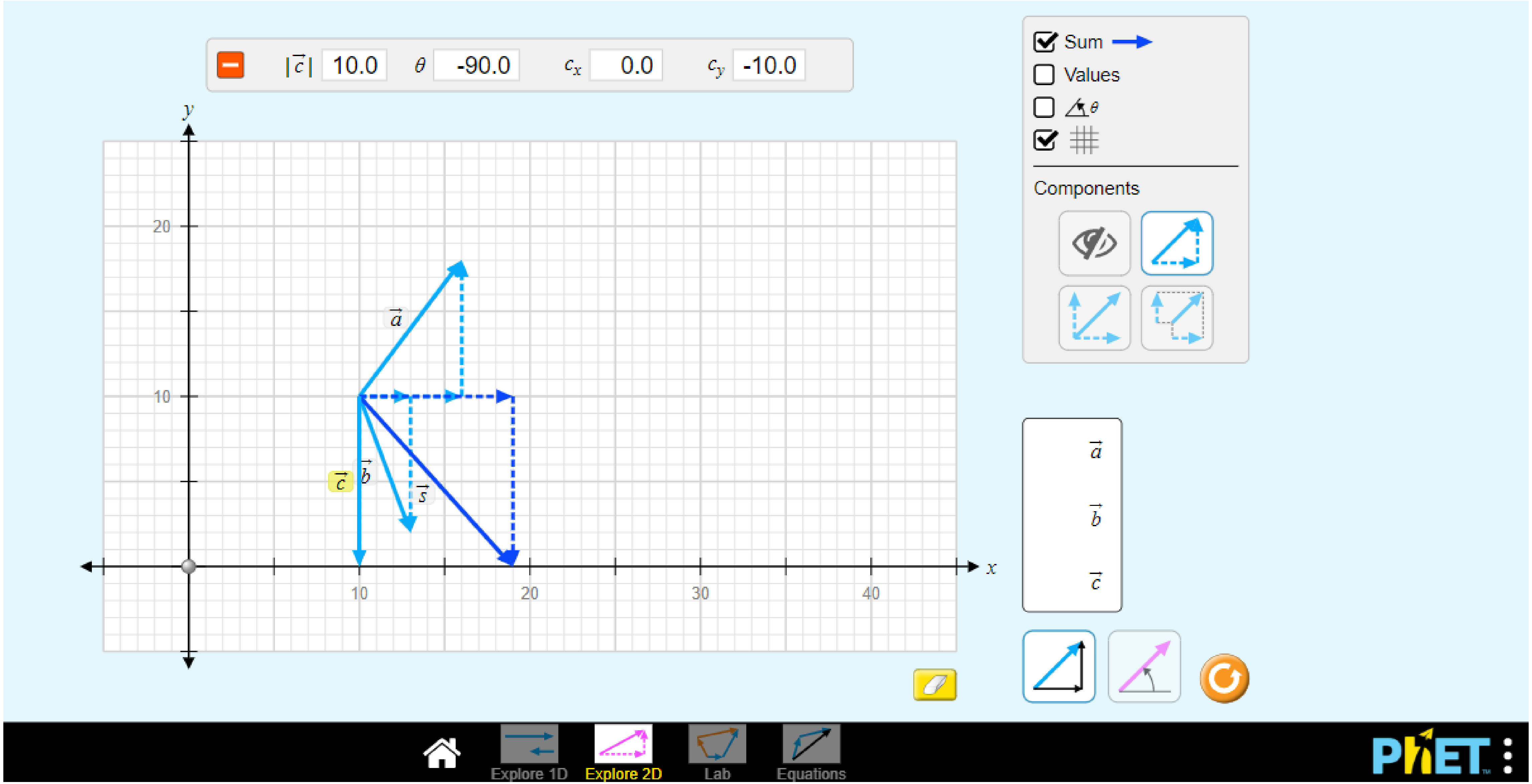
DOT PRODUCT

CROSS PRODUCT

$$\vec{A} \cdot \vec{B}$$
$$= (A_x B_x) + (A_y B_y) + (A_z B_z)$$

$$\vec{A} \times \vec{B}$$
$$= \hat{x}(A_y B_z - AzB_y) - \hat{y}(A_x B_z - AzB_x)$$
$$+ \hat{z}(A_x B_y - AyB_x)$$

INTERACTIVE PRESENTATION



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

LECTURE-02

Newton's Law

Free Body Force Diagram

CONCEPT QUESTION

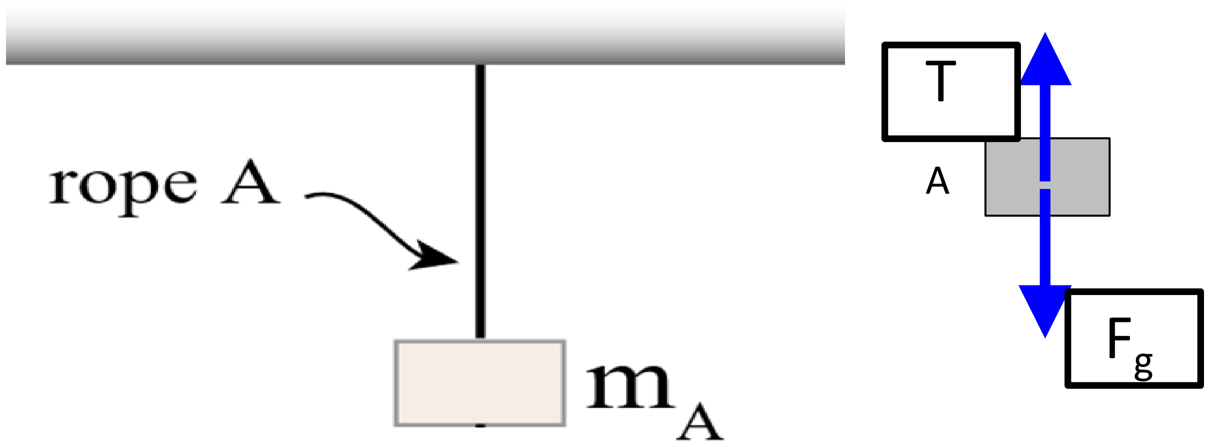
Mass m_A is hanging from a rope and resting without any motion or acceleration – equilibrium force pair T_A and F_g represent

A. Newton's First Law

B. Newton's Second Law

C. Newton's Third Law

D. None of the above



CONCEPT QUESTION

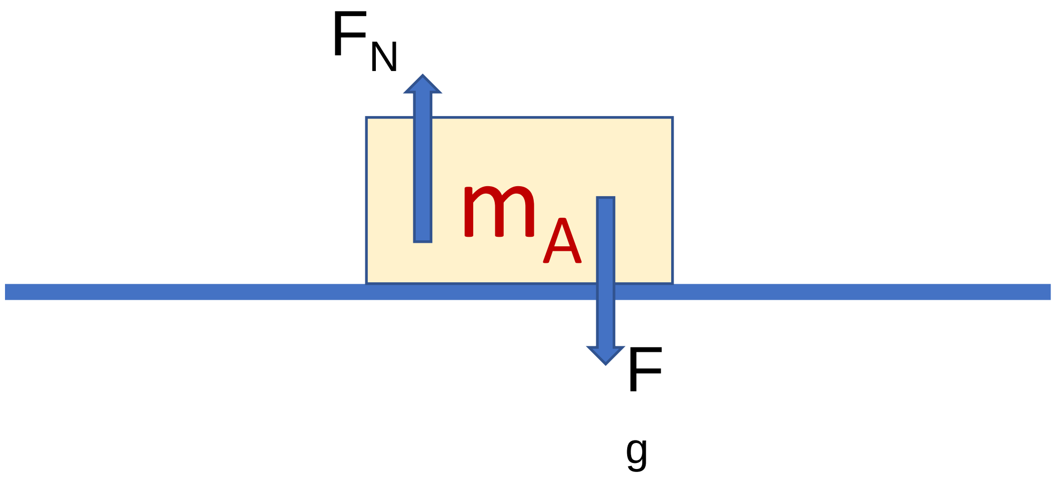
Mass m_A is resting on a table without any motion or acceleration – equilibrium force pair F_N and F_g represent

A. Newton's First Law

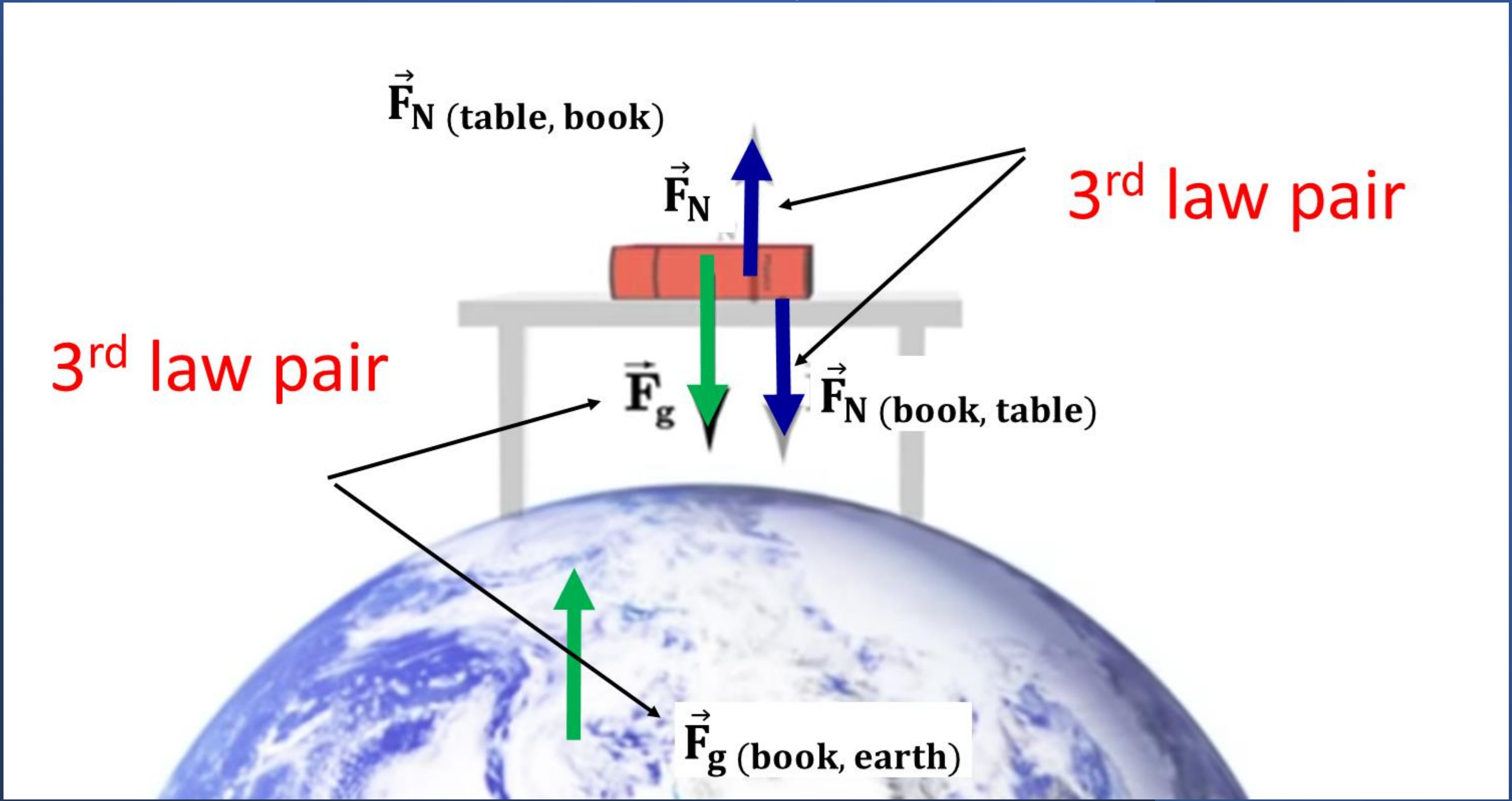
B. Newton's Second Law

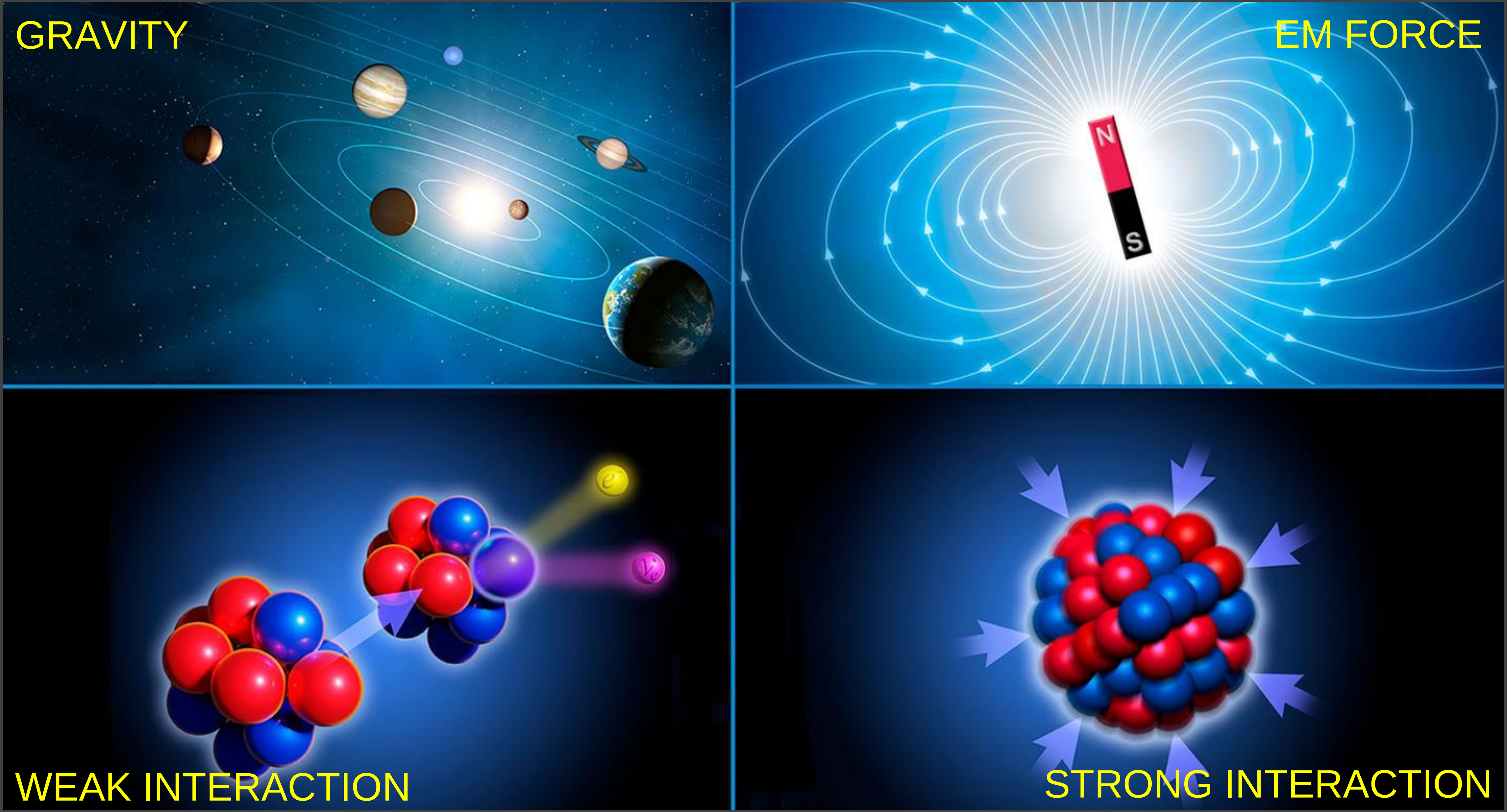
C. Newton's Third Law

D. None of the above



CONCEPT QUESTION




GRAVITY
EM FORCE
N
S
WEAK INTERACTION
STRONG INTERACTION

Contact & Non-contact Forces

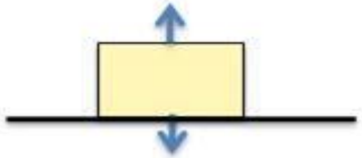
Contact forces: interactions between objects that touch

applied force

spring force

drag force

frictional force



normal force

Non-contact forces: attract or repel, even from a distance

magnetic force

electric force

gravitational force

'Newton's Laws of Motion'

1st

In the absence of external forces, when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity (that is, with a constant speed in a straight line).

2nd

When viewed from an inertial reference frame, the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

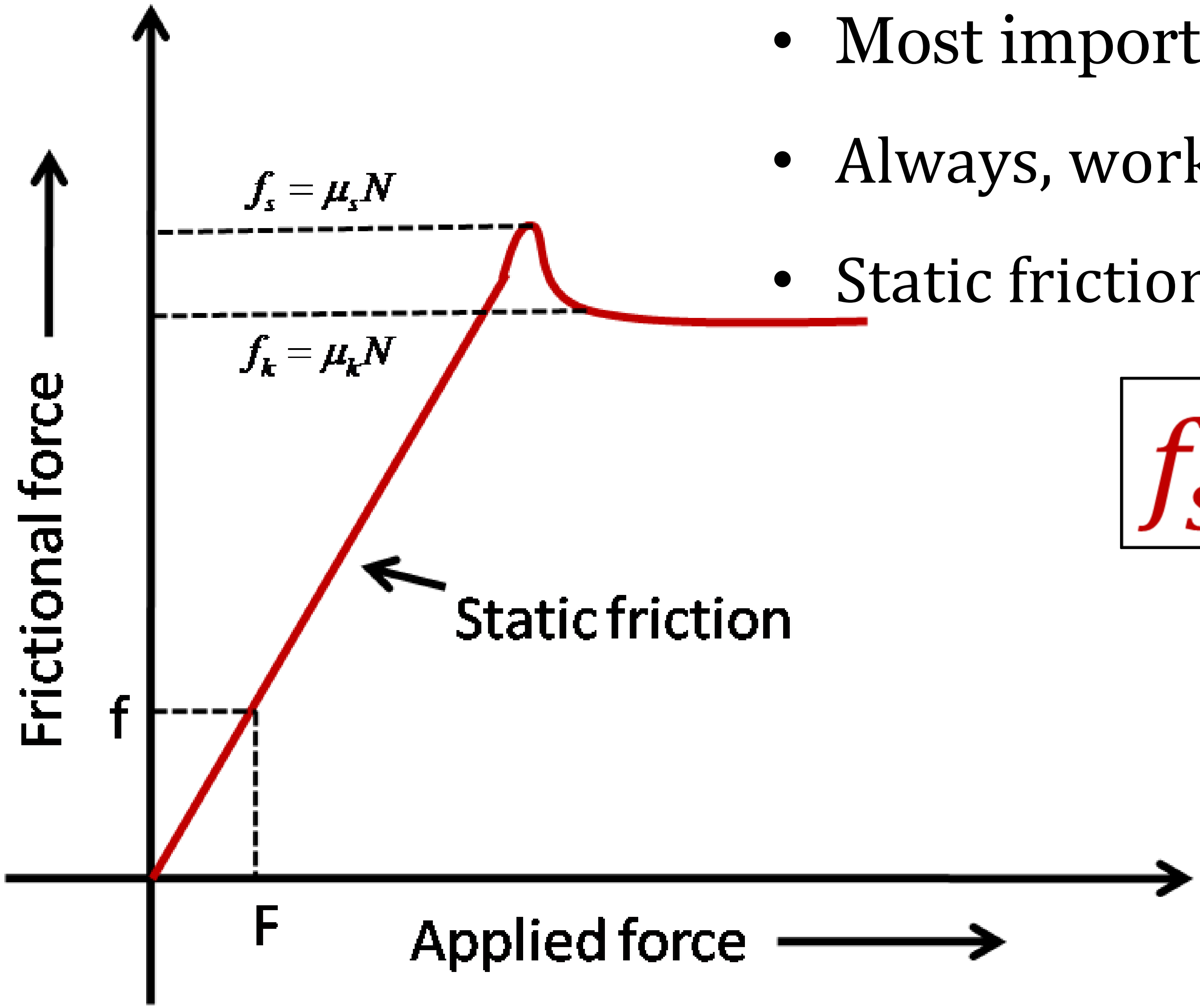
$$\sum \mathbf{F} = m\mathbf{a}$$

3rd

If two objects interact, the force $\mathbf{F}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\mathbf{F}_{21}$ exerted by object 2 on object 1:

$$\mathbf{F}_{12} = -\mathbf{F}_{21}$$

Revisiting friction

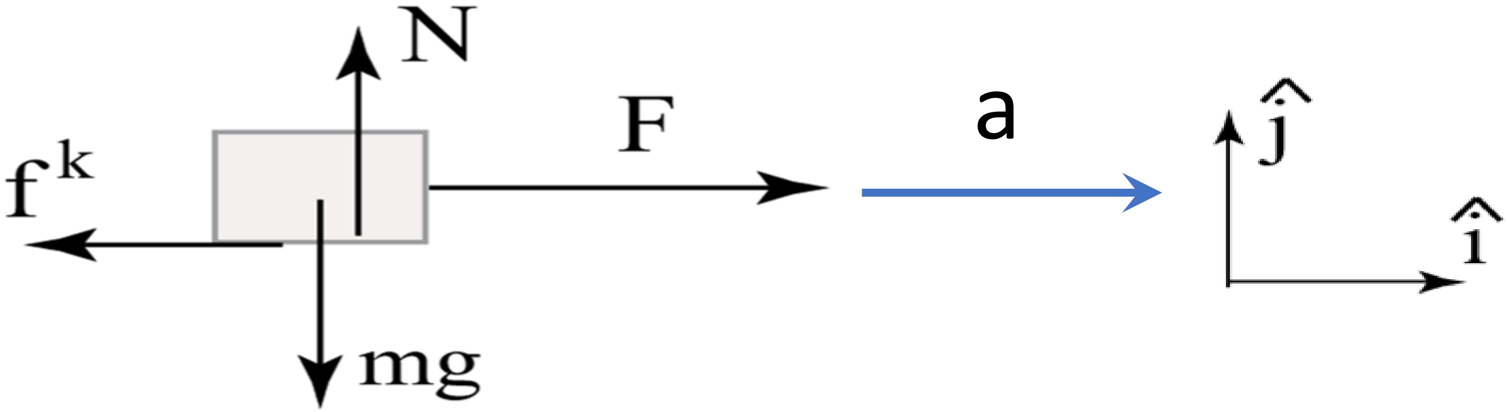


- Most important contact force in mechanics.
- Always, work opposite to the applied force F.
- Static friction (f_S) and kinetic friction (f_k)

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

$$\boxed{f_k = \mu_k . N}$$

Newton’s law from free body diagram



$$\boxed{\begin{aligned} a_x &= a \\ a_y &= 0 \end{aligned}}$$

$$\sum F_x = ma_x$$

$$F - f_k = ma_x$$

$$F - \mu_k N = ma$$

$$F - \mu_k mg = ma$$

$$\sum F_y = ma_y$$

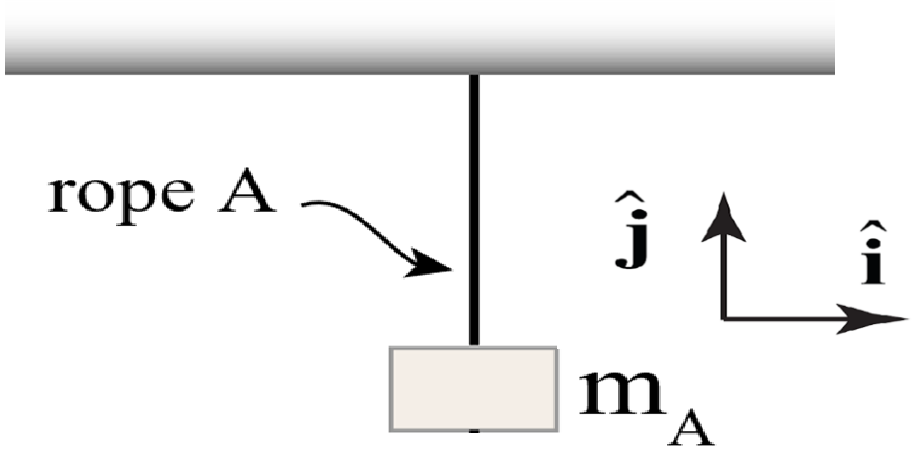
$$N - mg = ma_y$$

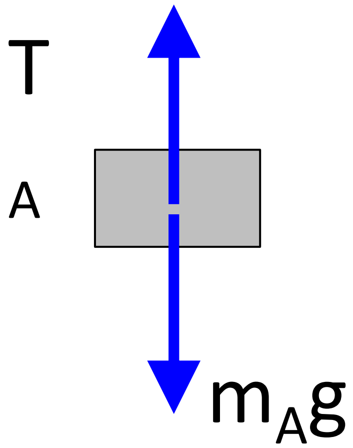
$$\boxed{N = mg}$$

since $a_y = 0$

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

Object hanging and at rest



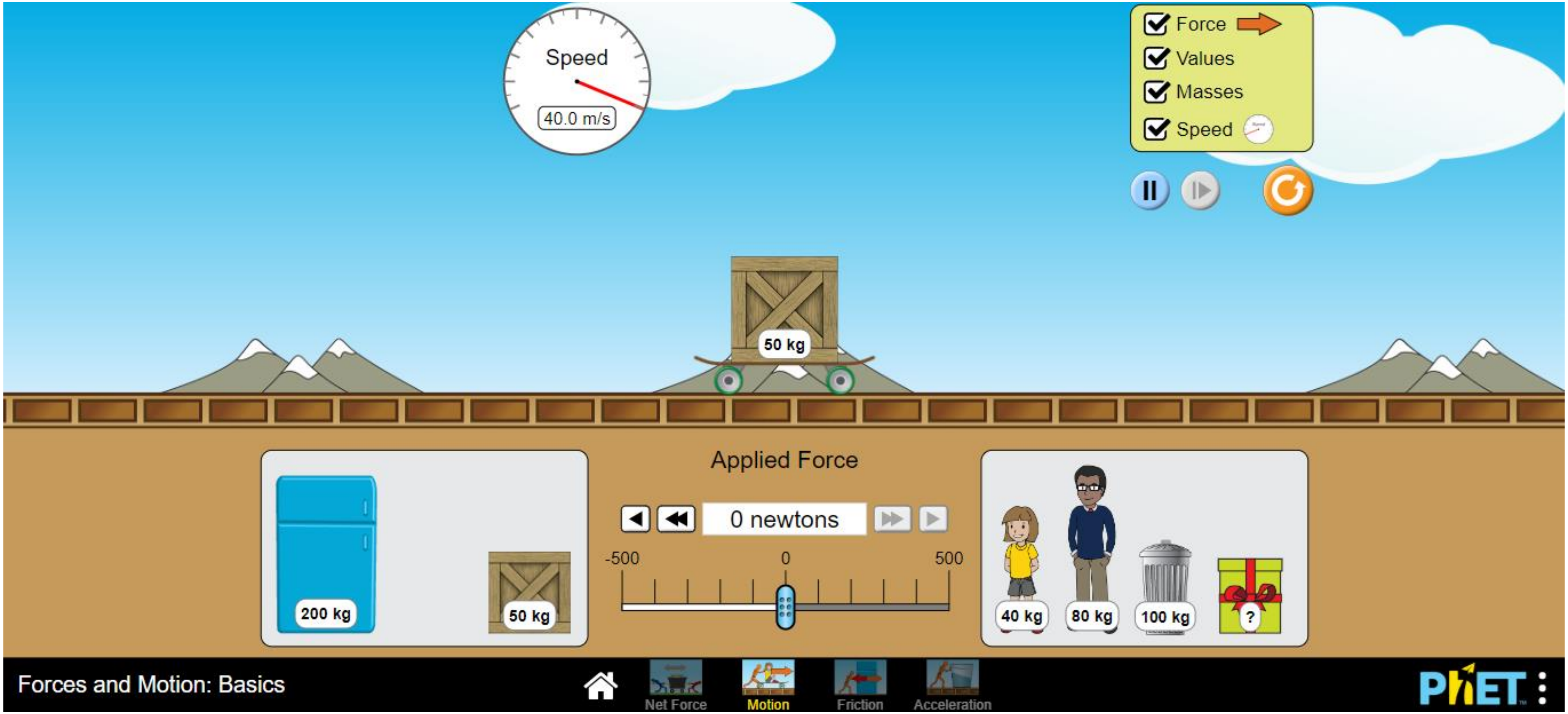


$$\boxed{\sum \vec{F} = m\vec{a}}$$

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

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

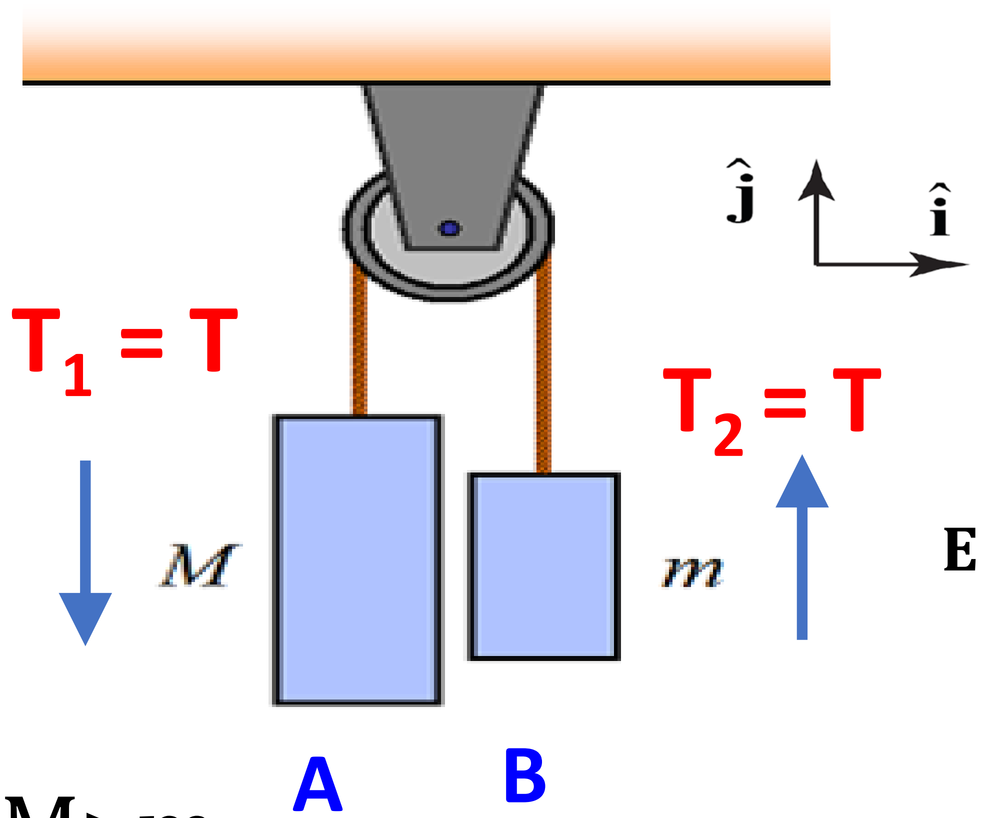
INTERACTIVE PRESENTATION



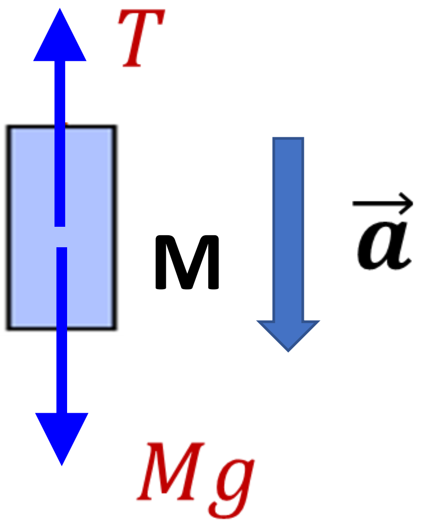
https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_en.html

Ideal Pulley system

- Rope-pulley is frictionless and $I_{cm} \sim 0$ i.e., **pulley at rest.**
- Rope/string is massless i.e., **uniform tension.**

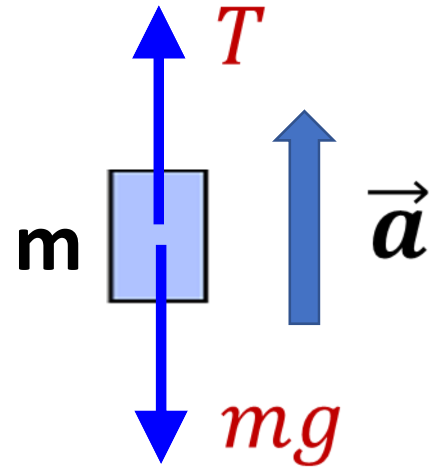


M>m



Eqn 1

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

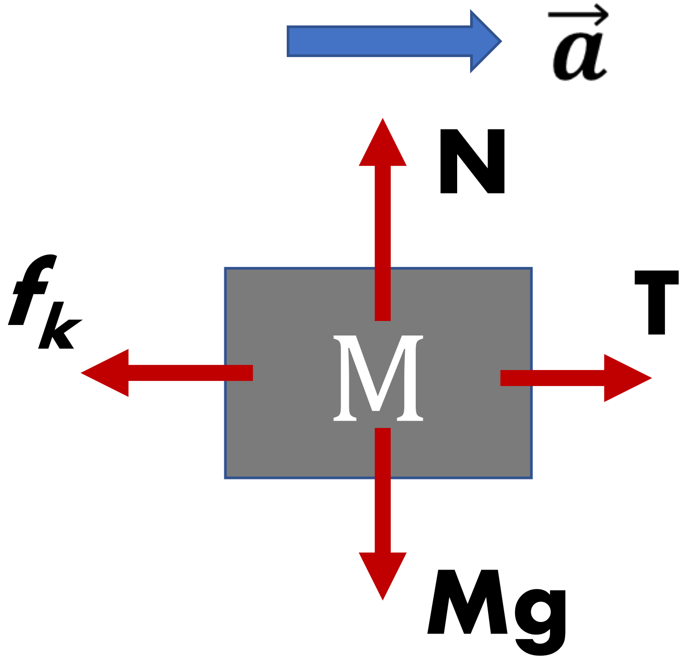


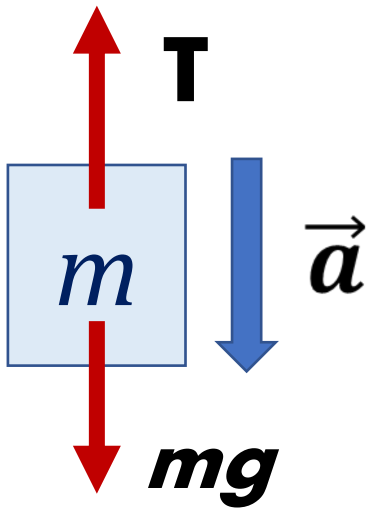
Eqn 2

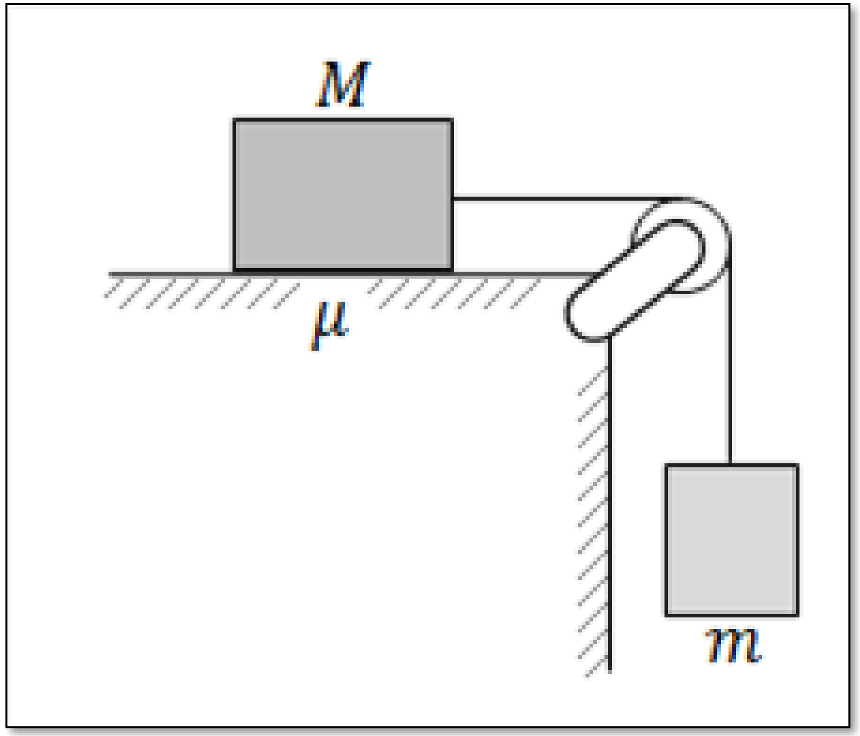
$$T - mg = m(+a)$$

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 pulley.







$$\left.\begin{aligned} Ma &= T - f_k \ (1) \Rightarrow Ma = T - \mu_k N \\ m(-a) &= T - mg \ (2) \end{aligned}\right\} \quad \boxed{a = \left(\frac{m - \mu_k M}{m + M}\right) g}$$

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 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 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

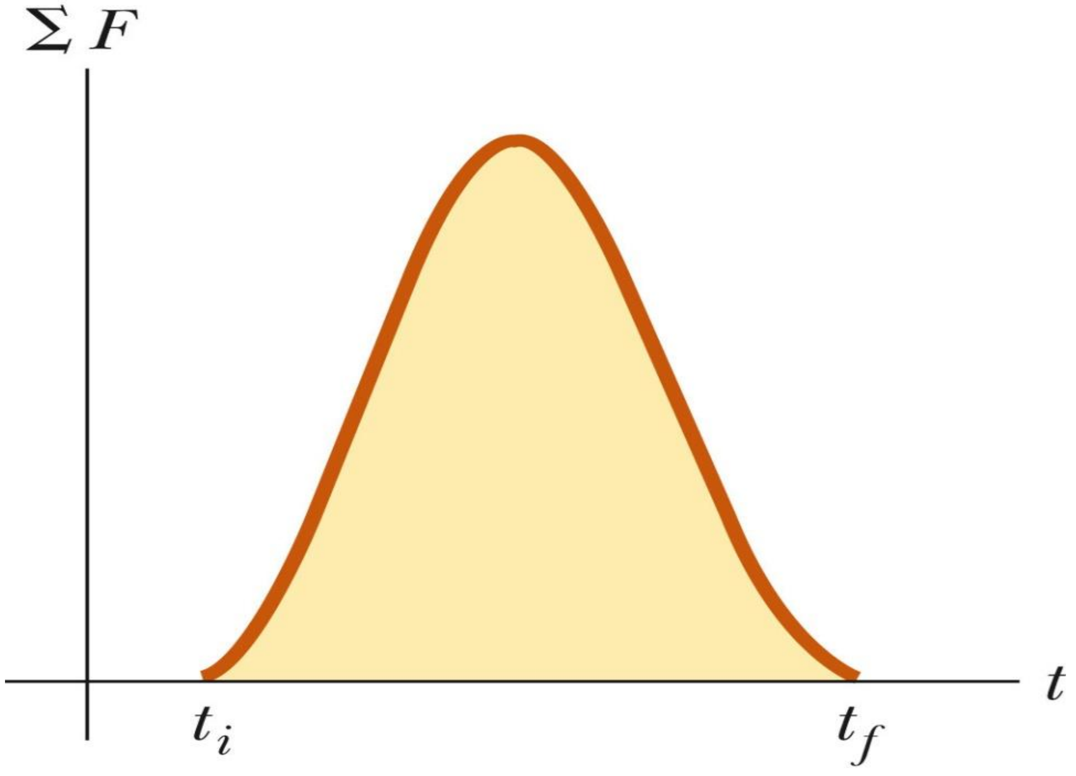
B. 900 Kg.m/s

C. 1050 Kg.m/s

D. 1250 Kg.m/s

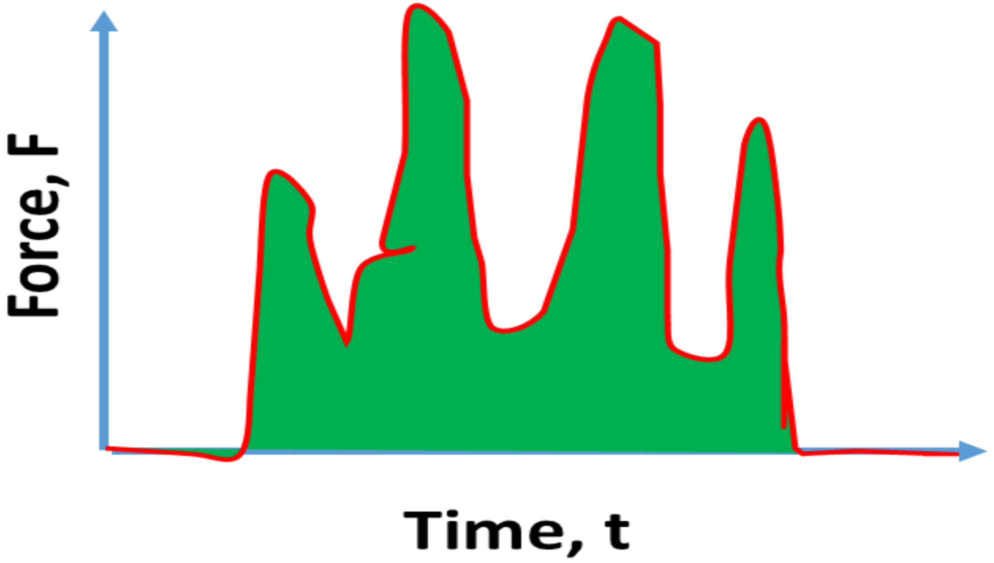
Impulse

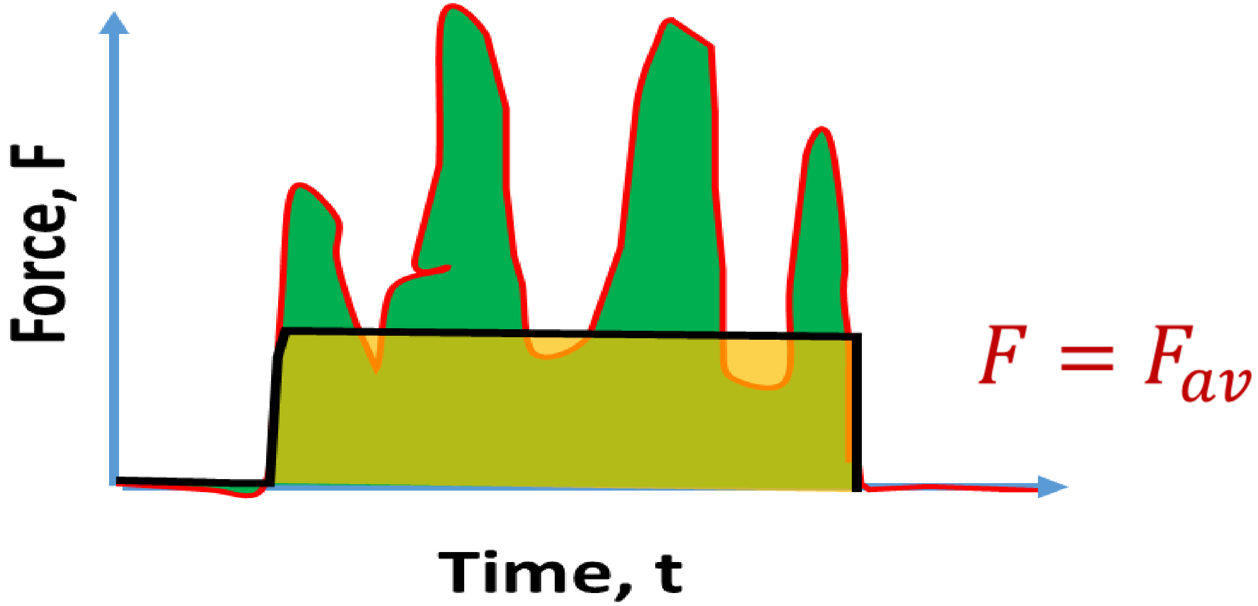
- Impulse is a vector quantity
- The magnitude of the impulse is equal to the area under the force-time curve
- The force may vary with time
- Dimensions of impulse are **M L / T**
- Impulse is not a property of the particle, but a measure of the change in momentum of the particle



Unit => Kg m/s

Force and impulse





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

Linear momentum

DEFINITION:

$$\vec{p} = m\vec{v} \qquad \text{(linear momentum of a particle)}$$

in which m is the mass of the particle and **v** is its velocity.
(This is a conserved (invariant) quantity for an isolated system.)
The time rate of change of the momentum of a particle is equal to the net force acting on the particle and is in the direction of that force.

$$\vec{F}_{\text{net}} = \frac{d\vec{p}}{dt}.$$

This is actually Newton's 2^{nd} law:

$$\vec{F}_{\text{net}} = \frac{d\vec{p}}{dt} = \frac{d}{dt}(m\vec{v}) = m\frac{d\vec{v}}{dt} = m\vec{a}.$$

Force-momentum-impulse

$$\int_{t=t_i}^{t=t_f} \vec{F}(t).dt = \int_{t=t_i}^{t=t_f} m.\vec{a}(t).dt = \int_{t=t_i}^{t=t_f} m.\frac{d\vec{v}(t)}{dt}.dt$$

$$\int_{t=t_i}^{t=t_f} \vec{F}(t).dt = \int_{t=t_i}^{t=t_f} \frac{d\{m.\vec{v}(t)\}}{dt}.dt = \int_{P_{t=t_i}}^{P_{t=t_f}} d\vec{P} = \vec{P}_f - \vec{P}_i = \Delta P$$

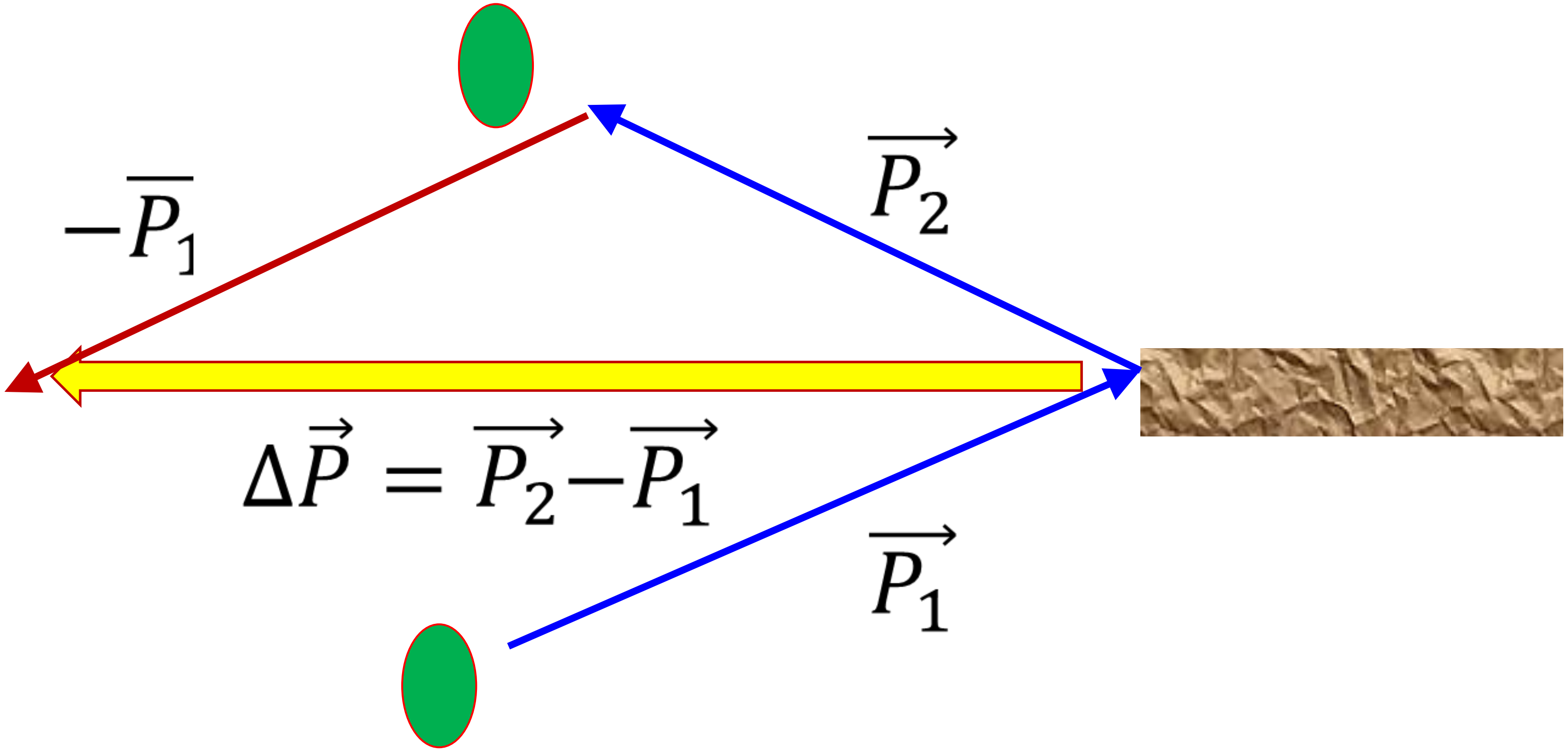
$$\int_{t=t_i}^{t=t_f} \vec{\boldsymbol{F}}(\boldsymbol{t}).\boldsymbol{dt} = \vec{\boldsymbol{P}}_f - \vec{\boldsymbol{P}}_i = \Delta\vec{\boldsymbol{P}} = \vec{\boldsymbol{I}} \Rightarrow \Delta\boldsymbol{P}_x = \boldsymbol{I}_x$$

Impulse-linear momentum theorem

The change in the linear momentum of a body is equal to the impulse that acts on that body.

Solved Example

Draw the impulse vector.

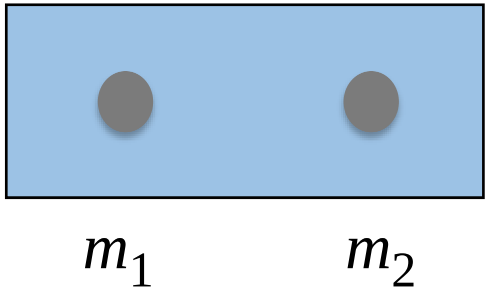


Conservation of Linear Momentum

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

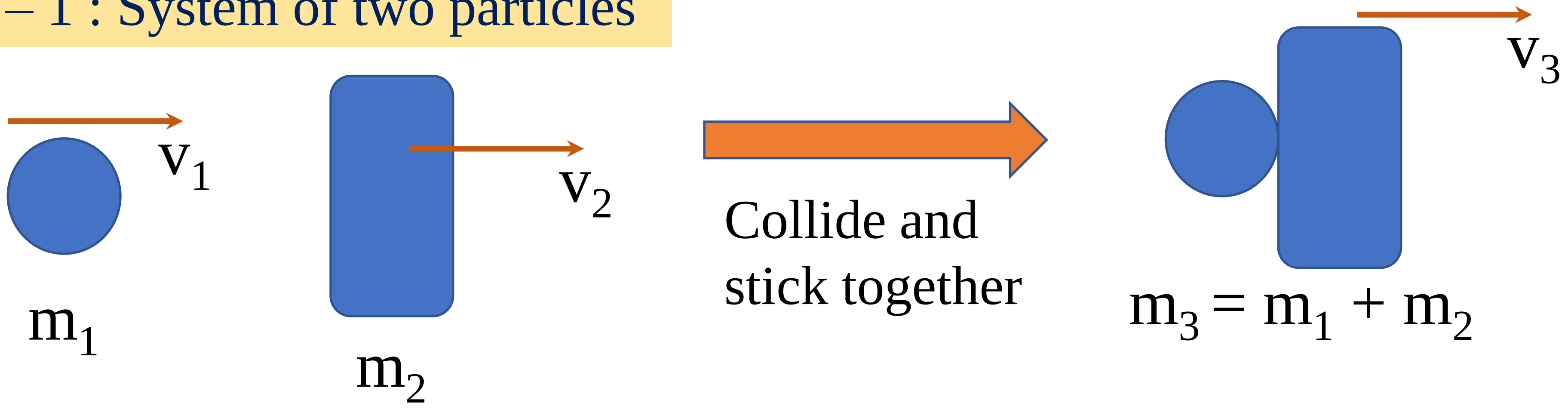
$$\frac{d\vec{p}_1}{dt} = -\frac{d\vec{p}_2}{dt} \qquad \frac{d(\vec{p}_1 + \vec{p}_2)}{dt} = \frac{d\vec{P}}{dt} = 0$$

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



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

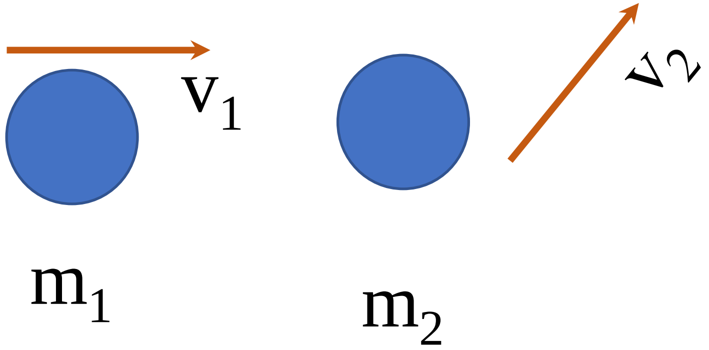
$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}_3$$

Change in Momentum after collision

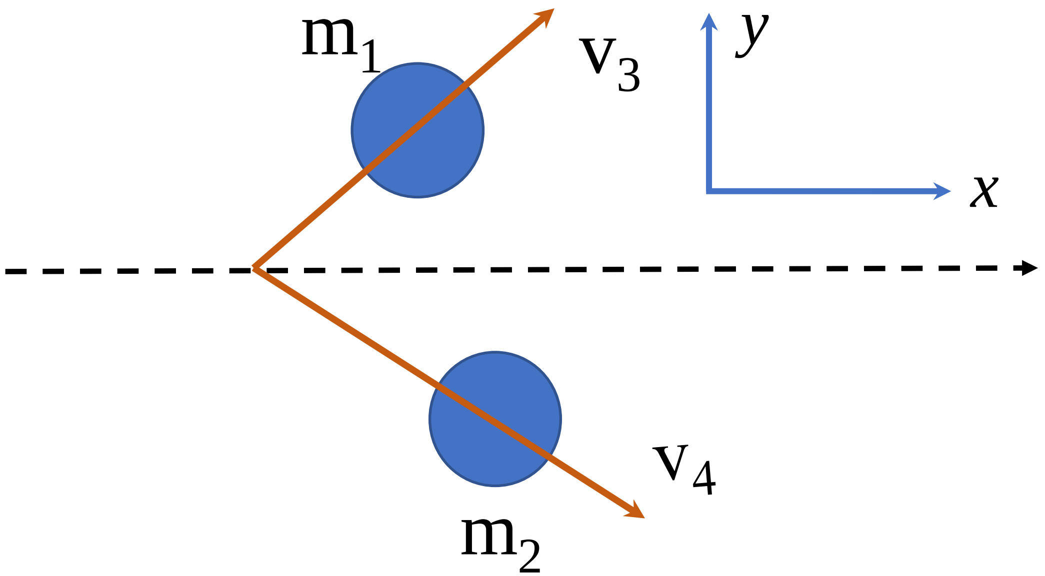
$$\Delta\vec{P}_{sys} = \vec{P}_{sys}(final) - \vec{P}_{sys}(initial)$$

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



Collide and scatter



1D COLLISIONS ONLY

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

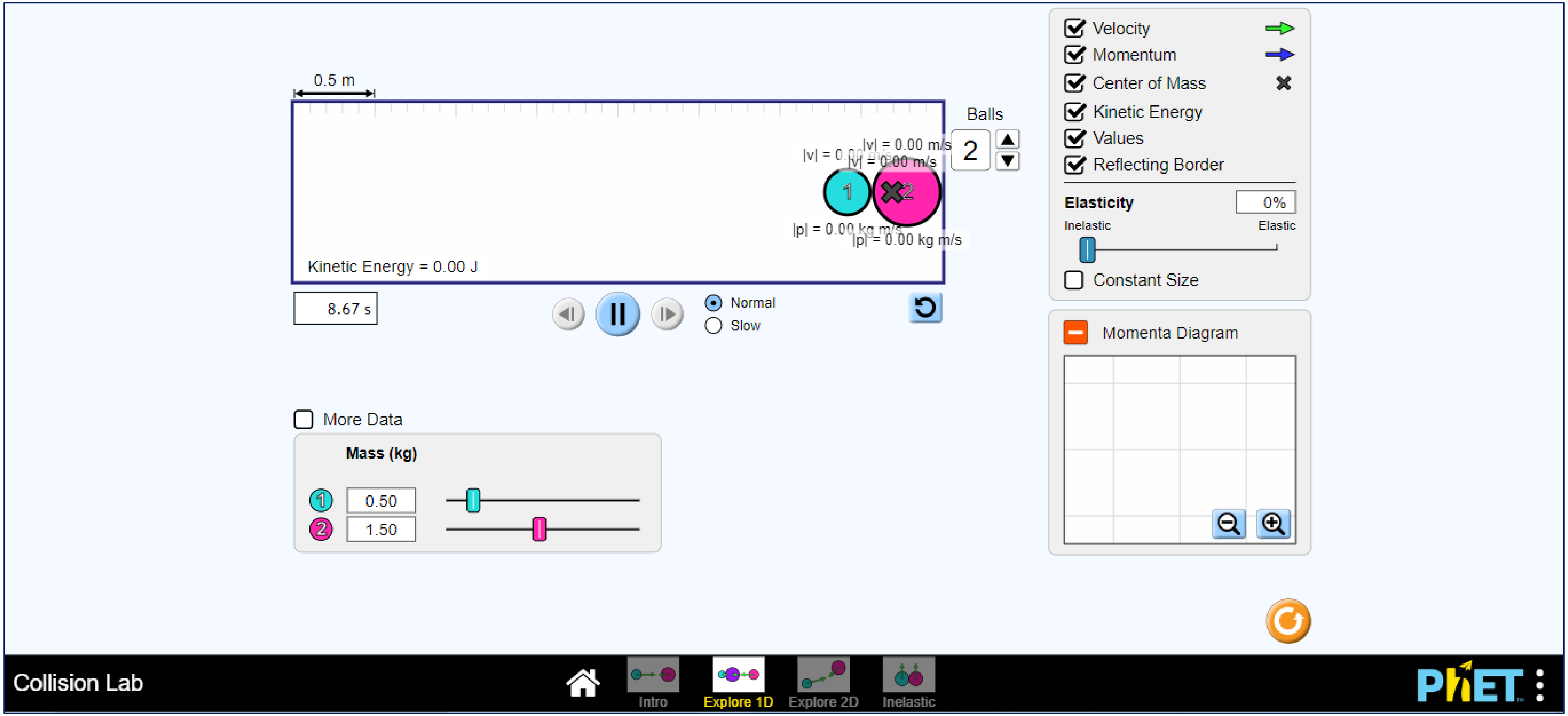
$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_3 + m_2\vec{v}_4$$

$$\Downarrow$$

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

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

INTERACTIVE PRESENTATION



https://phet.colorado.edu/sims/html/collision-lab/latest/collision-lab_en.html

POLL QUESTION

An estimated force-time curve for a cricket ball by a bat is shown in Figure.

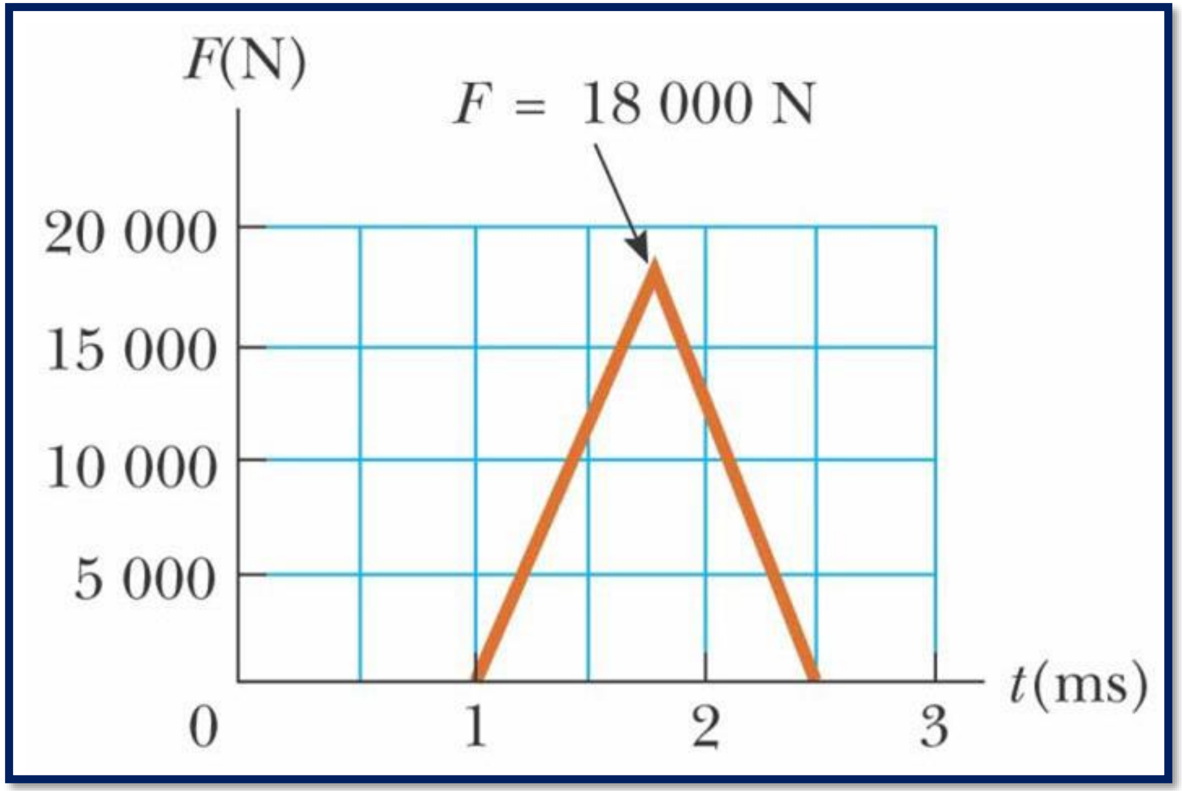
From this curve, determine the impulse delivered to the ball

A. 11.3 N.s

B. 13.5 N.s

C. 17.6 N.s

D. 19.4 N.s



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

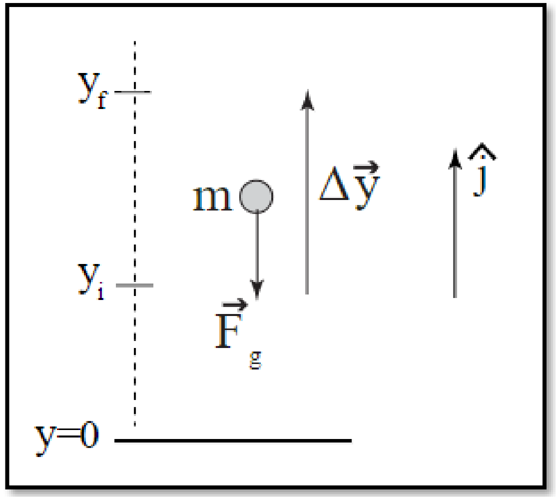
C. 7m/s

D. 11m/s

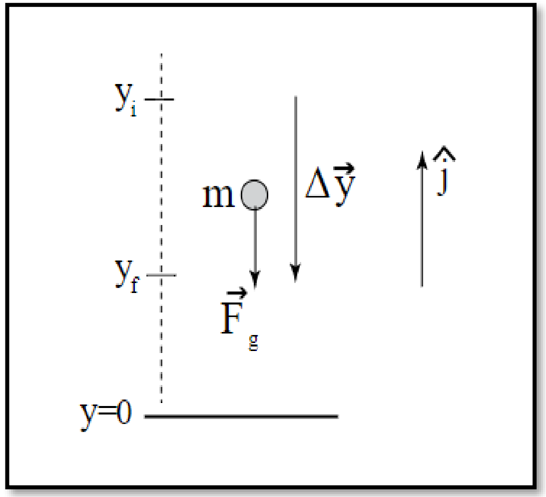
Work and Kinetic Energy

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

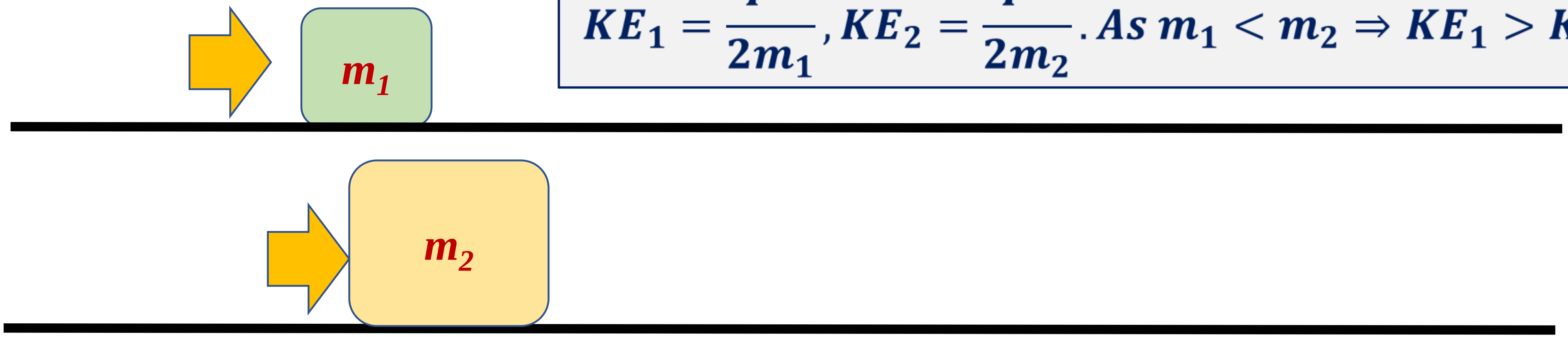
Two carts of masses ***m_1*** and ***m_2*** ***(=2m_1)*** are at rest on a horizontal and frictionless surface. Both cars are pushed with equal forces for the same time interval.

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

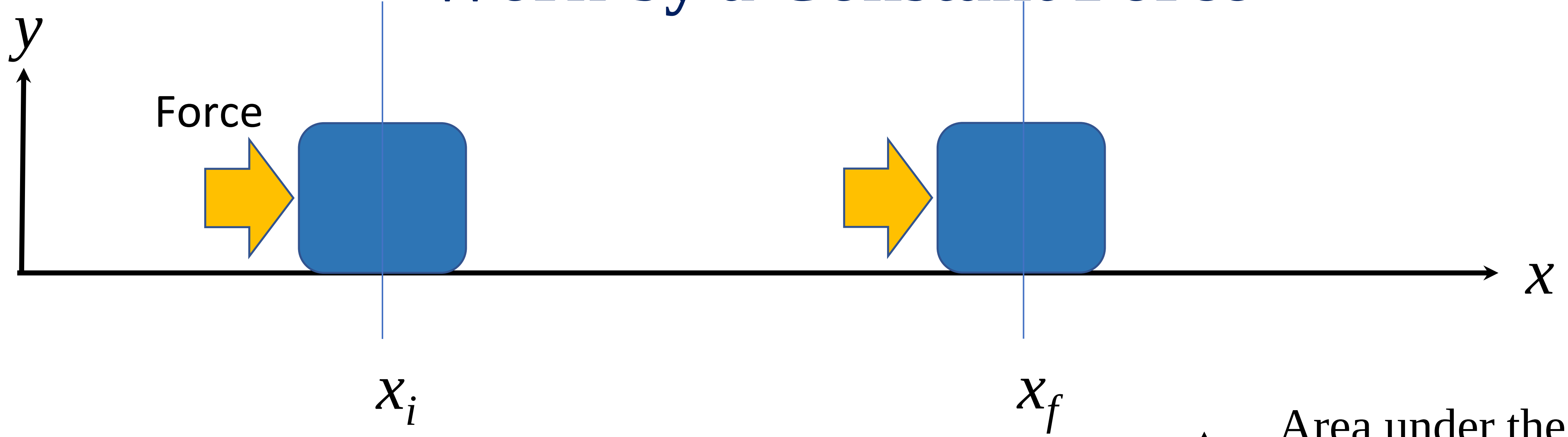
Ans: Cart with mass m_1.

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

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



Work by a Constant Force

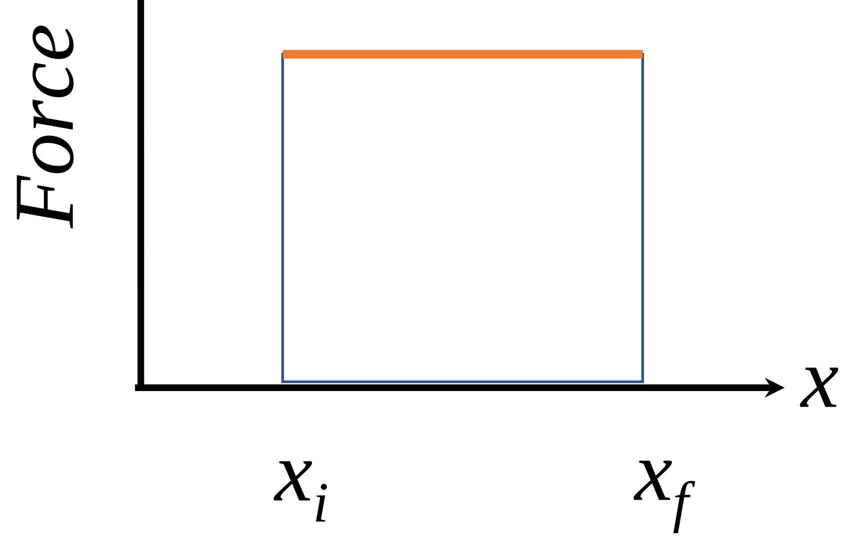


Work by a Constant Force $\vec{F}$ is **W**

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

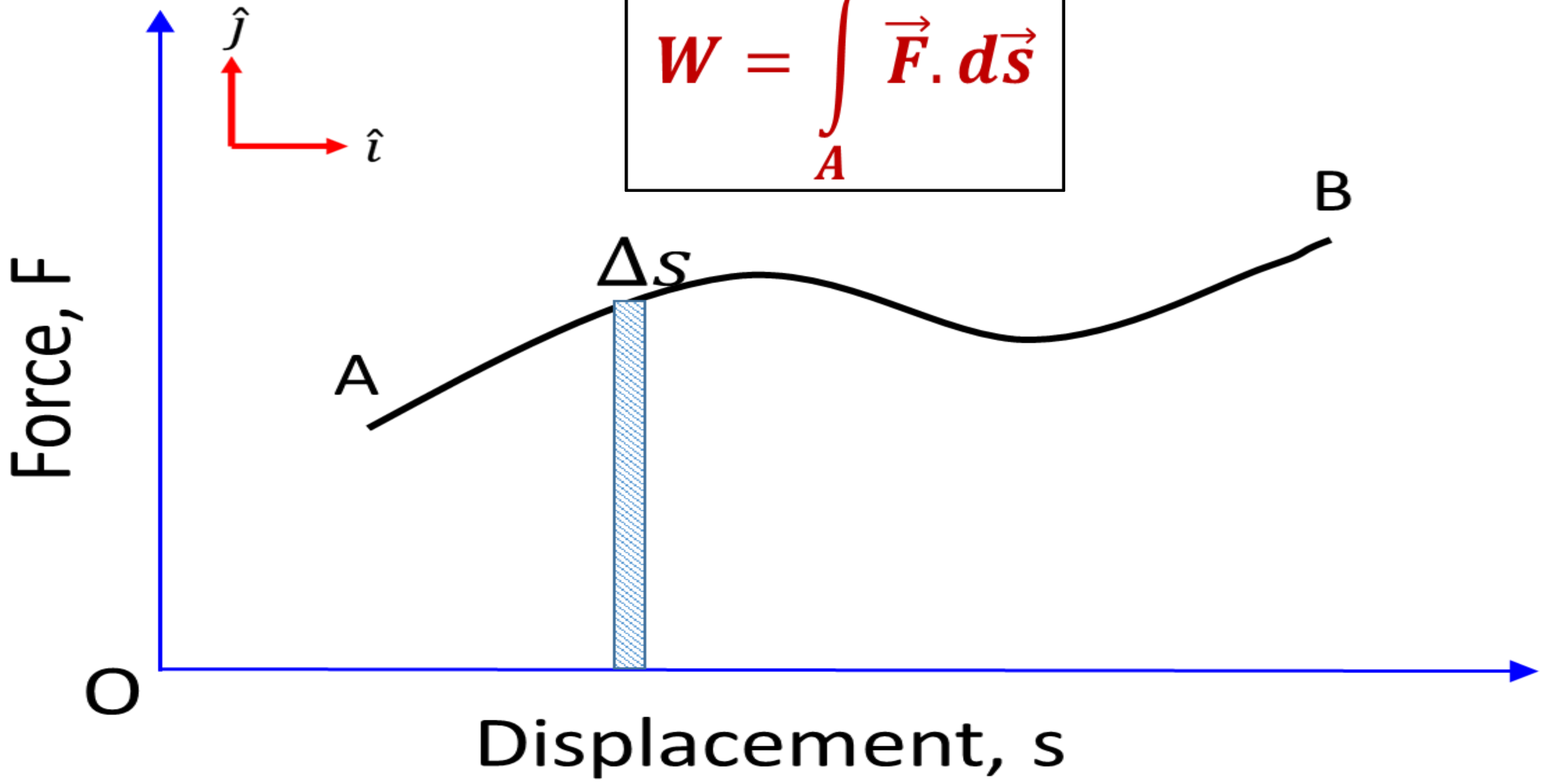
The SI unit of work is the *Joule (J)*, which is defined as the work expended by a force of one newton through a displacement of one metre.

Area under the Force vs. Distance curve



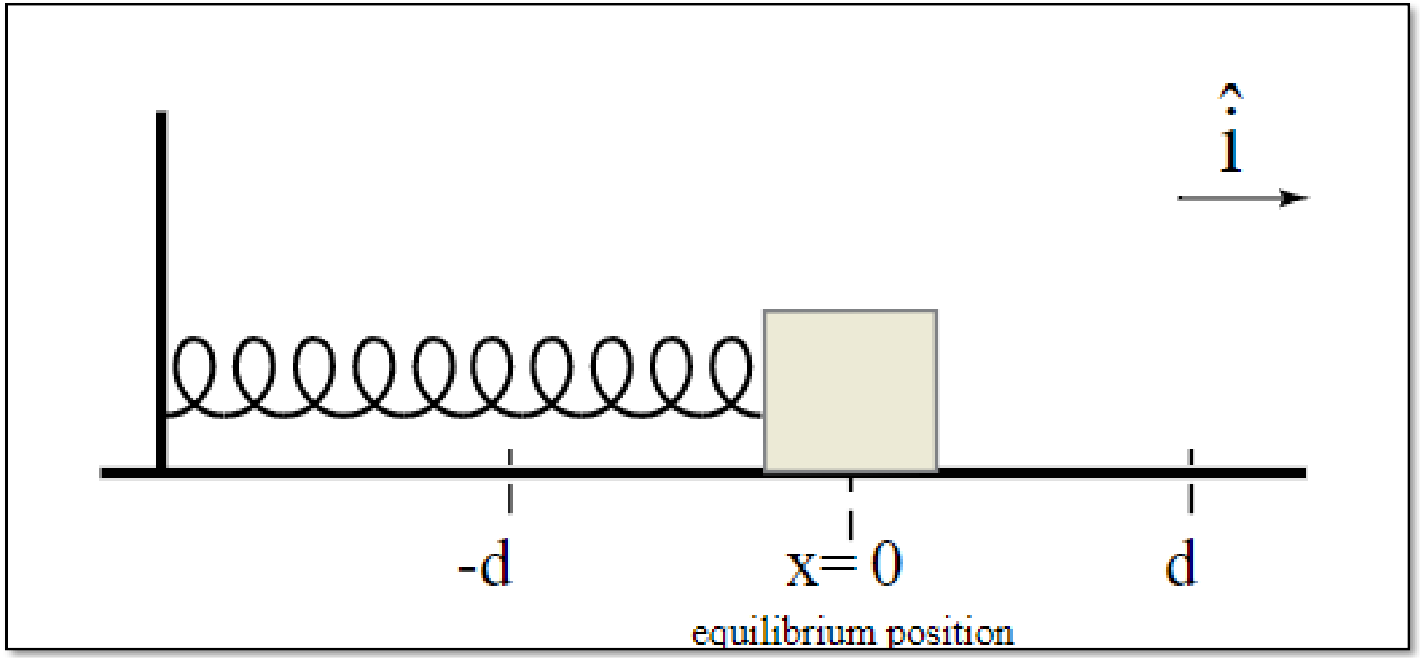
Work by a Non-Constant Force

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



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 $\vec{F}^s = F_x^s\,\hat{i} = -kx\,\hat{i}$. 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:

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

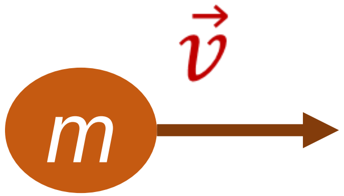
$$(a) W_{0\to d} = -\int_0^d kx dx = -\frac{1}{2}kd^2$$

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

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

Kinetic Energy & Work

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

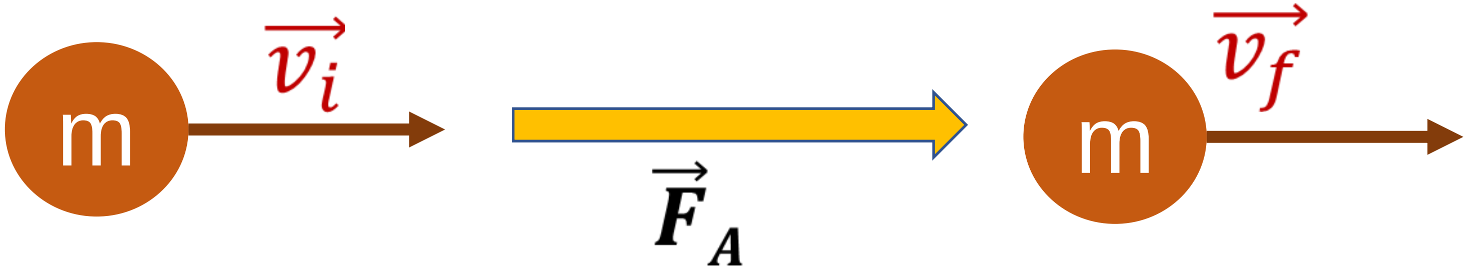


Kinetic energy K.E

$$= \frac{1}{2} m(\vec{v}.\vec{v}) = \frac{1}{2} m v^2$$

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

The work done on an object by a net force equals the change in kinetic energy of the object



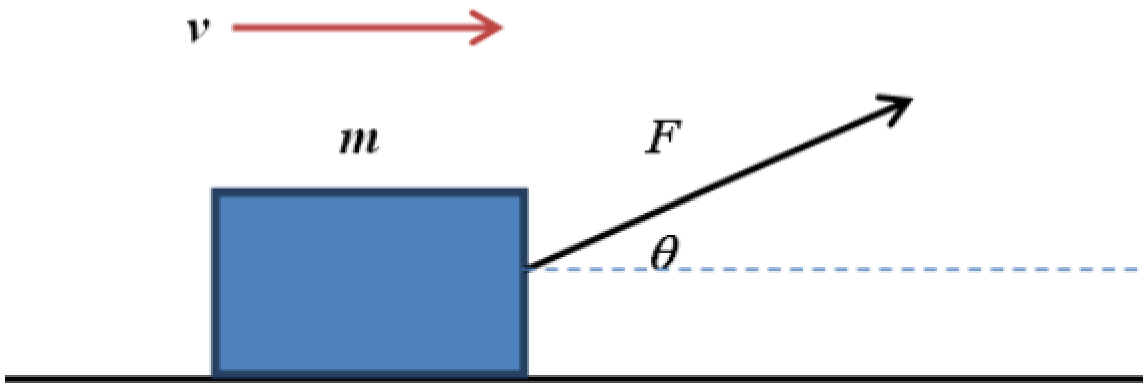
$$W = \int_A^B \vec{F}.\overrightarrow{ds} = \int_A^B \frac{\overrightarrow{dp}}{dt}.\overrightarrow{ds} = \int_A^B \frac{\overrightarrow{ds}}{dt}.\overrightarrow{dp} = \int_A^B \vec{v}.\overrightarrow{dp} = m\int_{v_i}^{v_f} \vec{v}.\overrightarrow{dv}$$

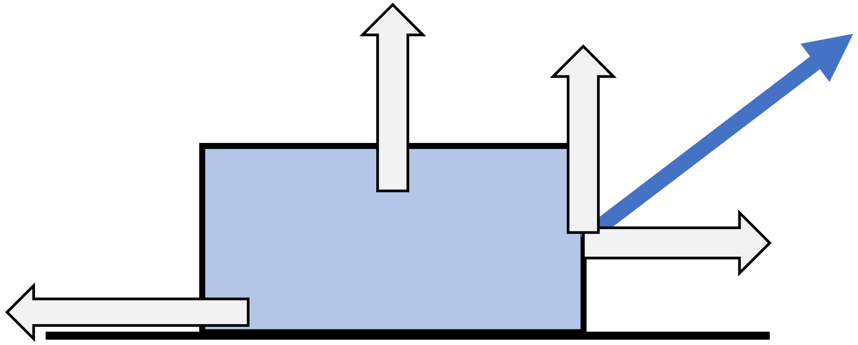
$$= \frac{1}{2} m {v_f}^2 - \frac{1}{2} m {v_i}^2 = \frac{1}{2} m({v_f}^2 - {v_i}^2) = \Delta\, KE$$

Work-KE Theorem

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

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

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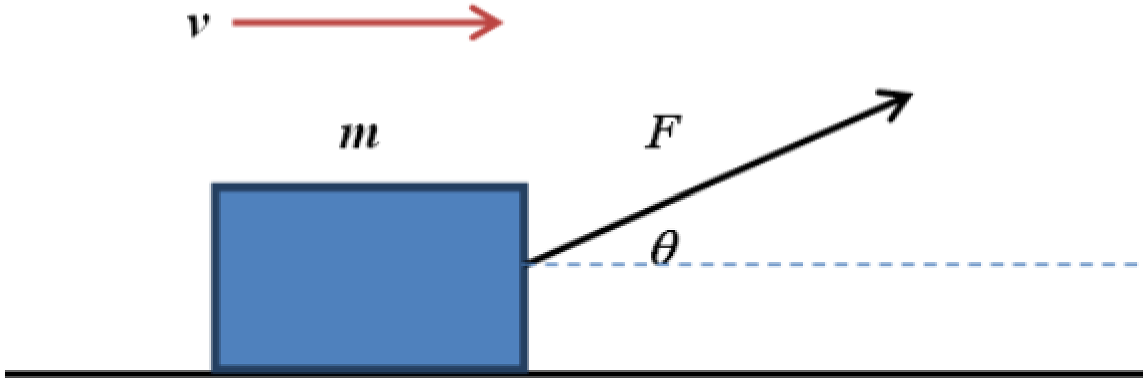

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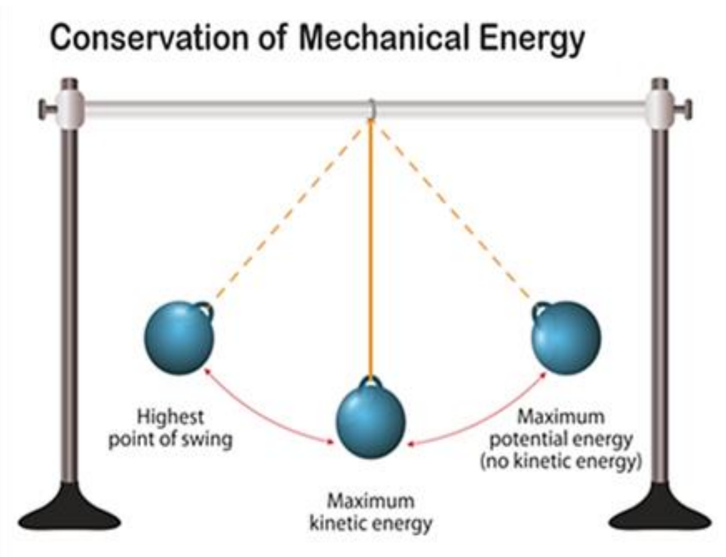
$$\vec{F}_{Appl} = FCos\theta\hat{\imath} + FSin\theta\hat{\jmath},$$
$$\vec{F}_{N.F.} = (mg - FSin\theta)(+\hat{\jmath}),$$
$$\vec{F}_{friction} = \mu_k(mg - FSin\theta)(-\hat{\imath})$$
$$\overrightarrow{\Delta x} = d(+\hat{\imath})$$

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

LECTURE-05



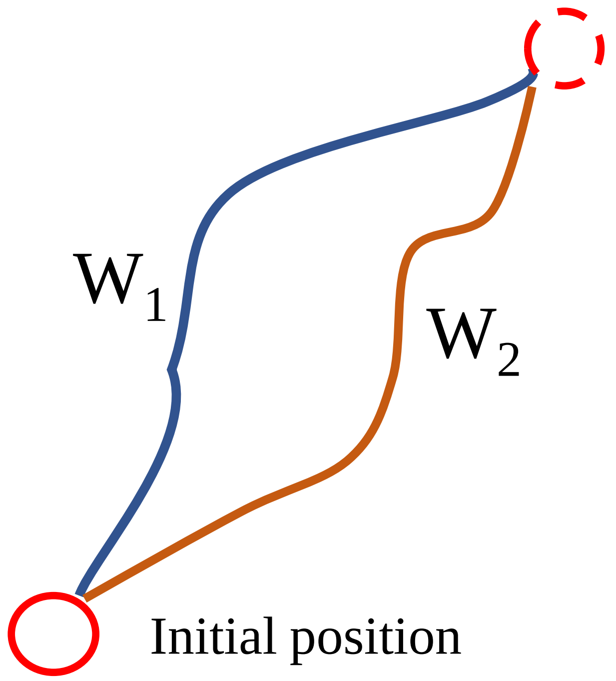
CONSERVATION OF MECHANICAL ENERGY

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

$$\boxed{W_1 = W_2 = \ldots\ldots = W_n}$$



Example - Gravitational force, Spring force, and electric force

Non - conservative force

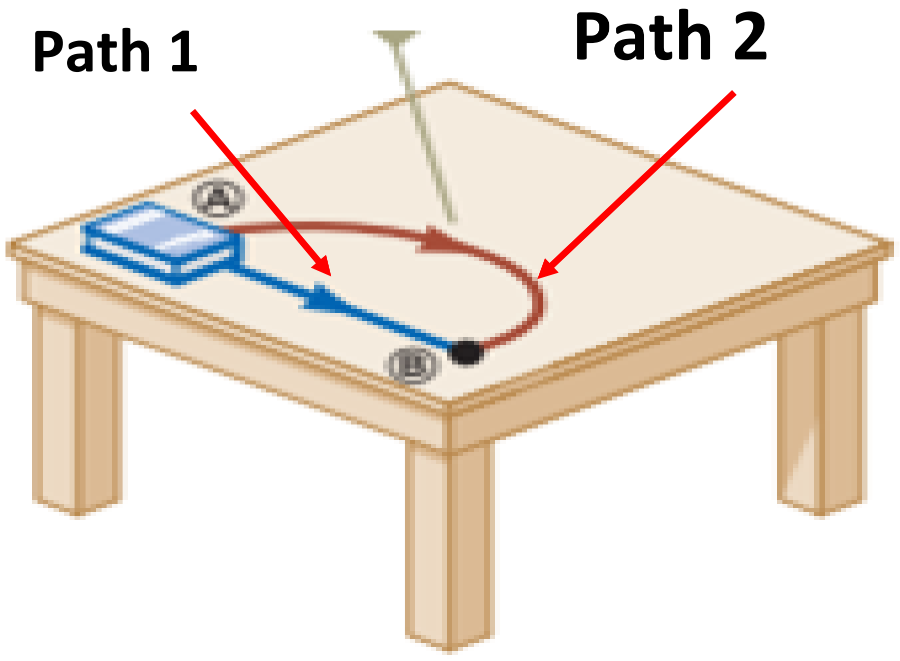
Whenever the work done by a force in moving an object from an initial point to a final point depends on the path, the force is called a non-conservative force.

$$\boxed{W_1 \neq W_2 \neq \ldots\ldots \neq W_n}$$

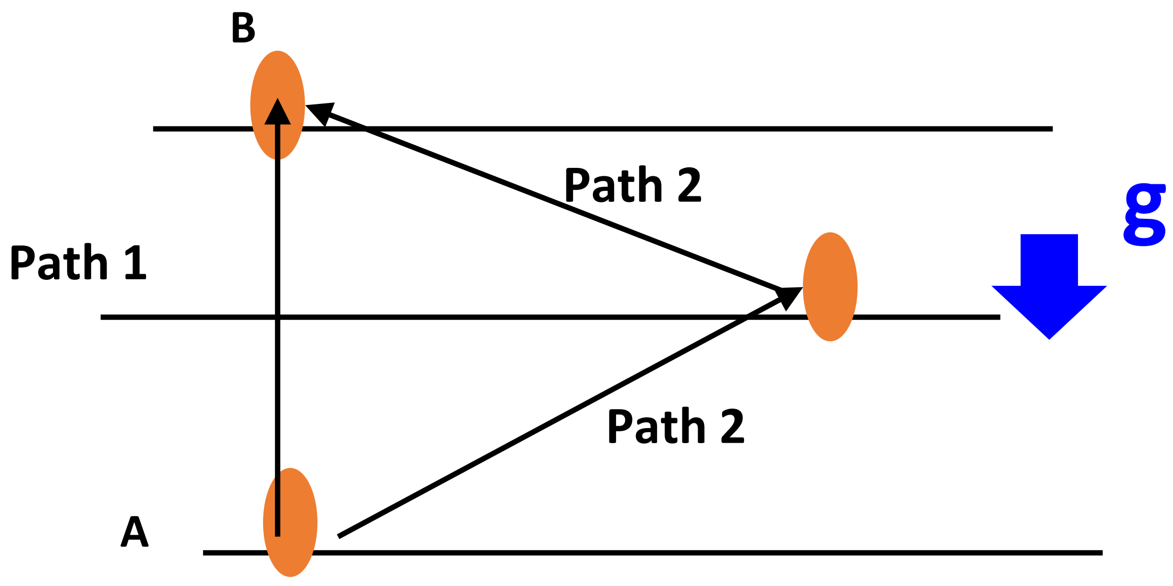
Example - Friction force and air drag force

Conservative and non-conservative forces

Example 1



Example 2



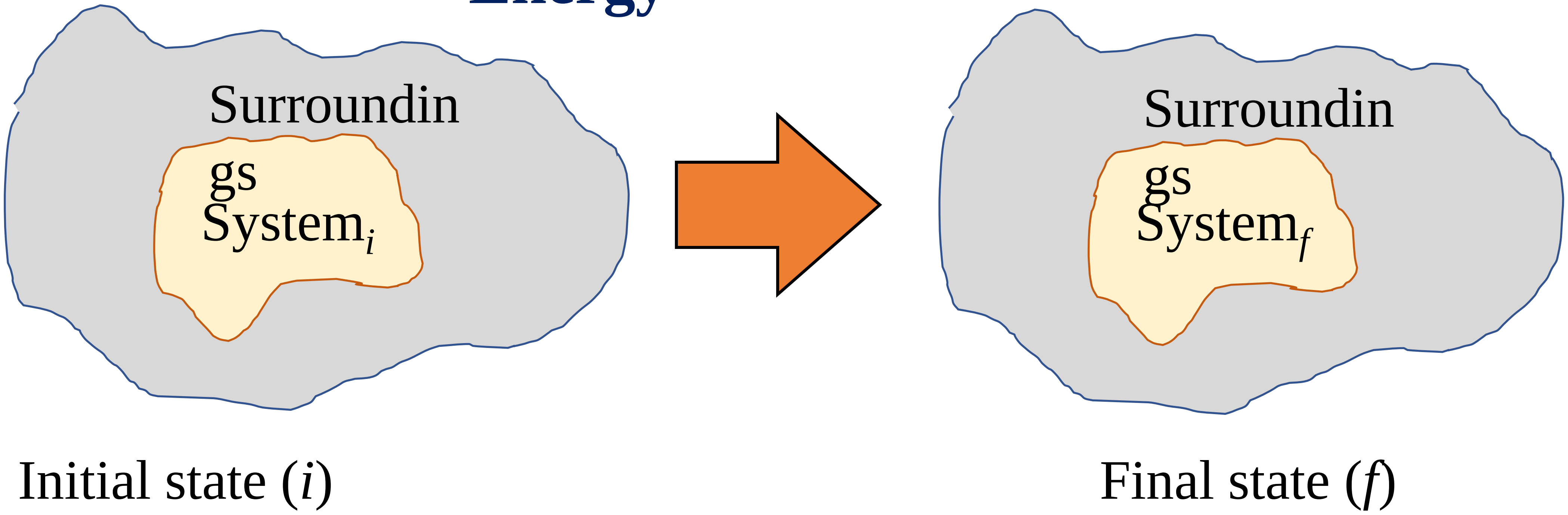
Friction: Non-conservative forces

$W_{A \text{ to } B}$ depends on the path

Gravity: Conservative forces

$W_{A \text{ to } B}$ does NOT depends on the path

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

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

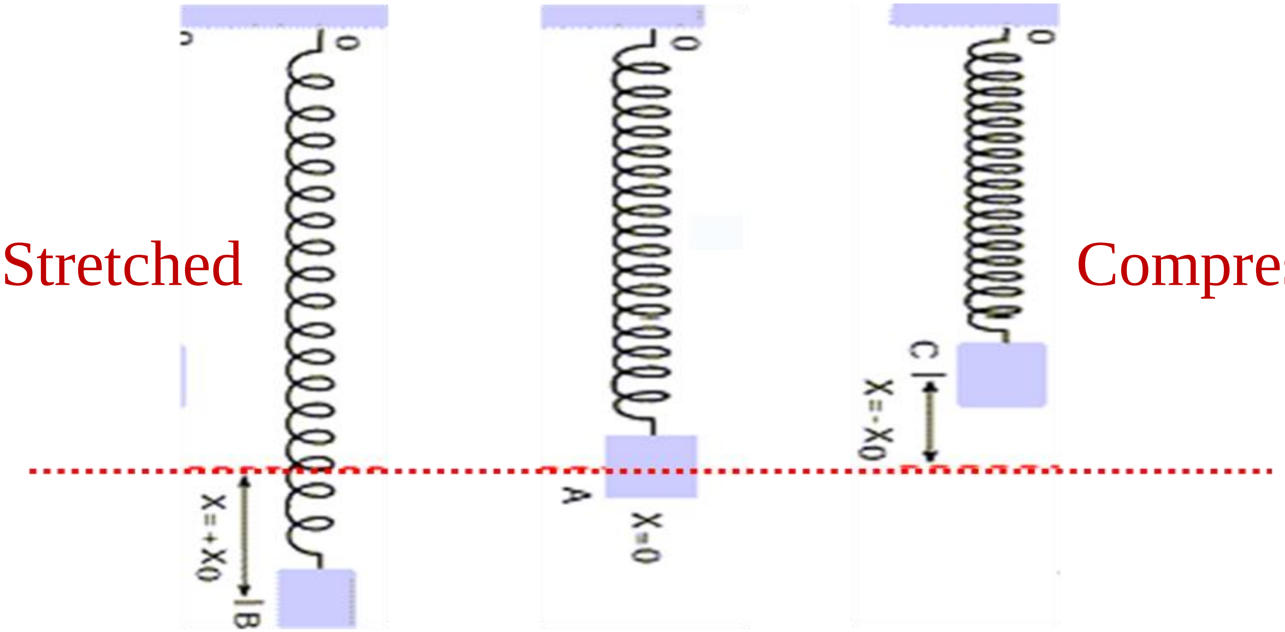
Potential energy due to Springs

Restoring force, F

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

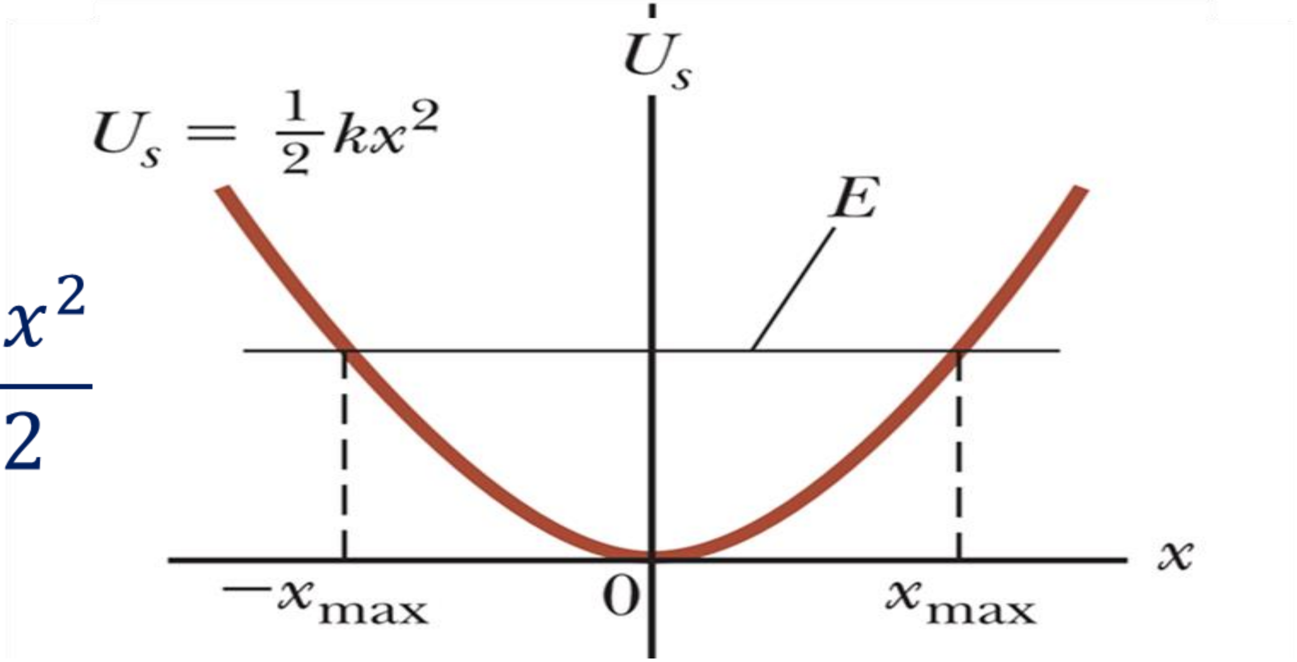
HOOKE'S LAW

Stretched

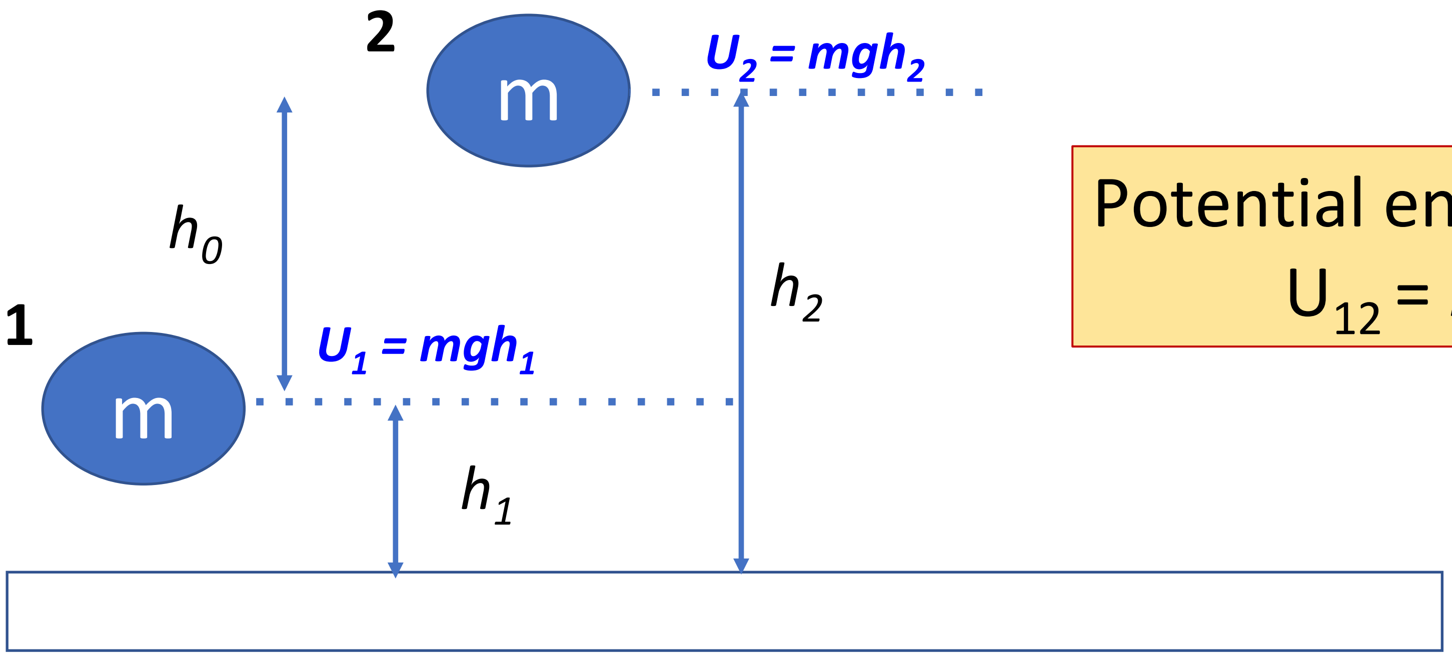


Compressed

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



Gravitational potential energy

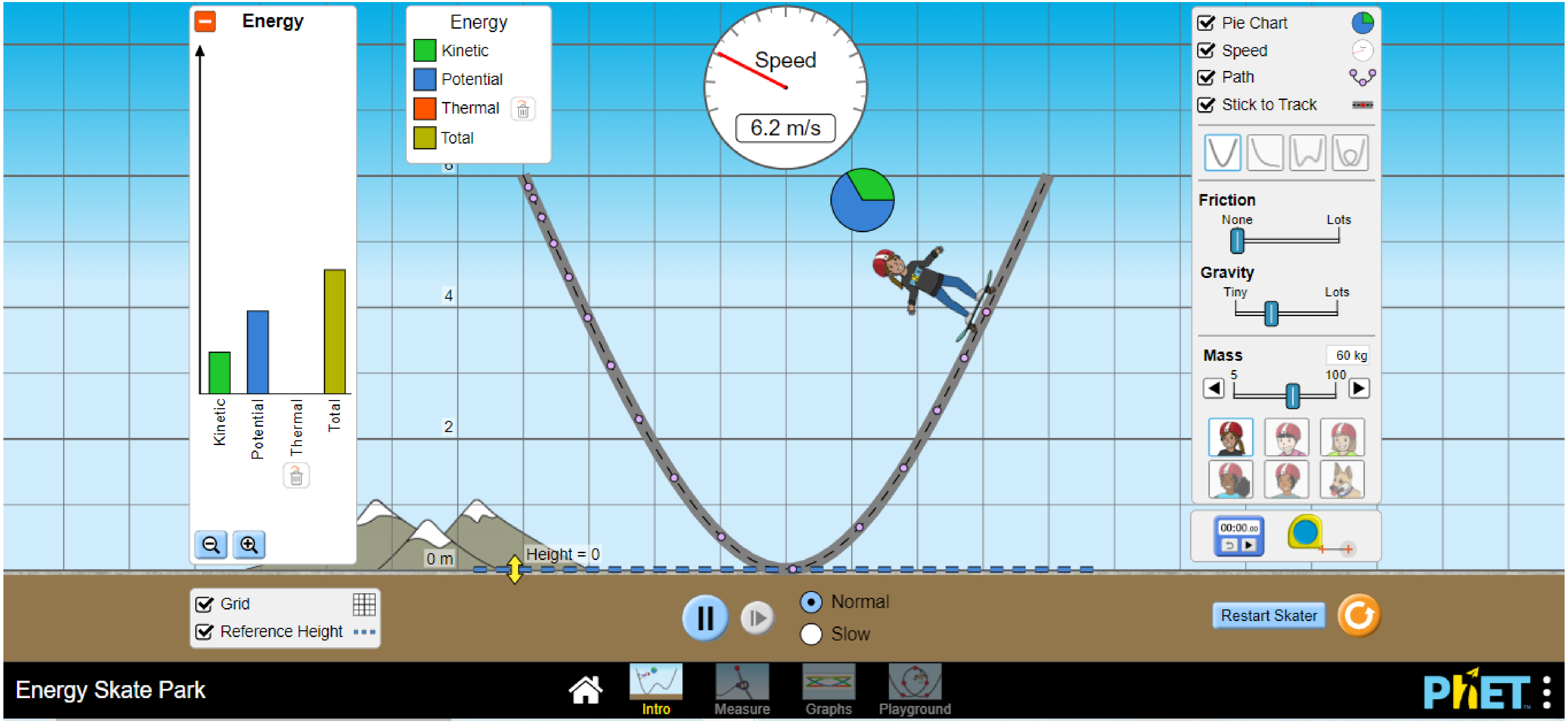


Potential energy change (from 1 to 2)

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

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

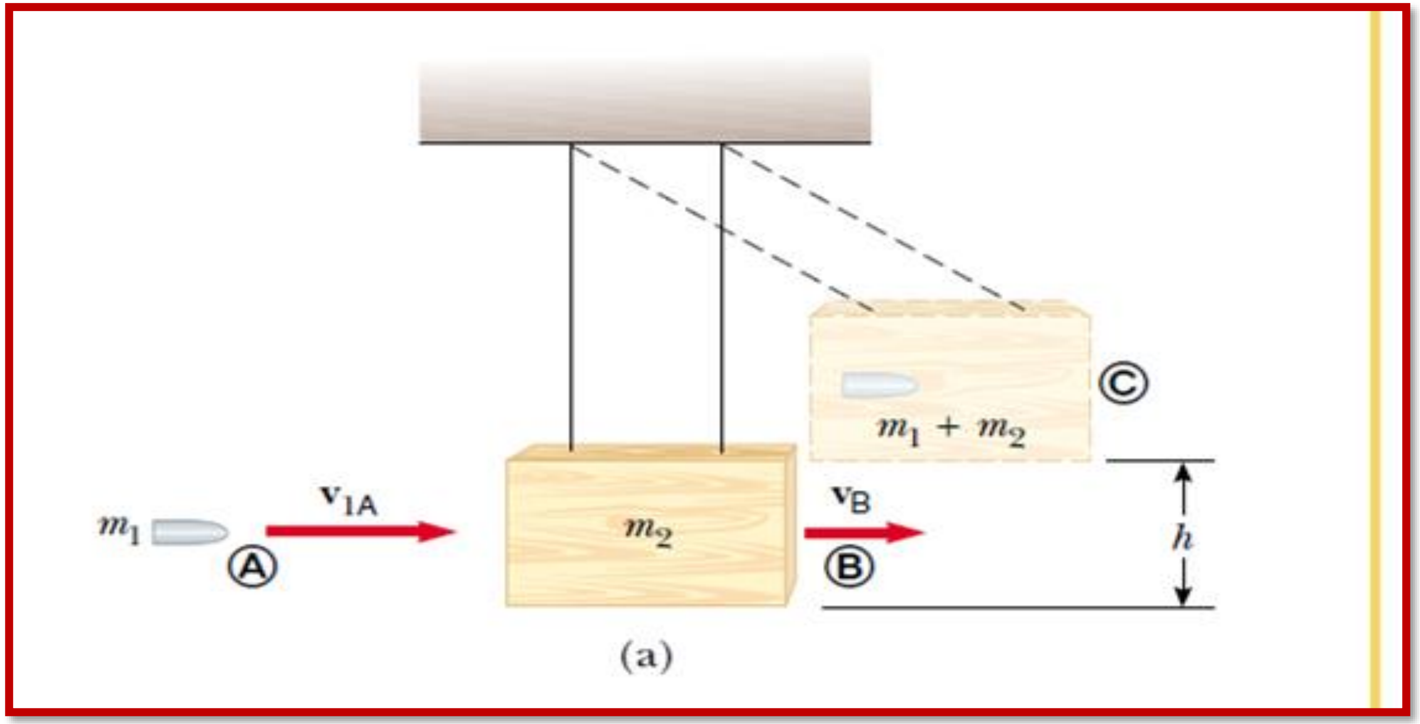
INTERACTIVE PRESENTATION



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

Conservation of Mechanical Energy

Ballistic Pendulum



$$v_B = \frac{m_1 v_{1A}}{m_1 + m_2}$$

$$K_B + U_B = K_C + U_C$$

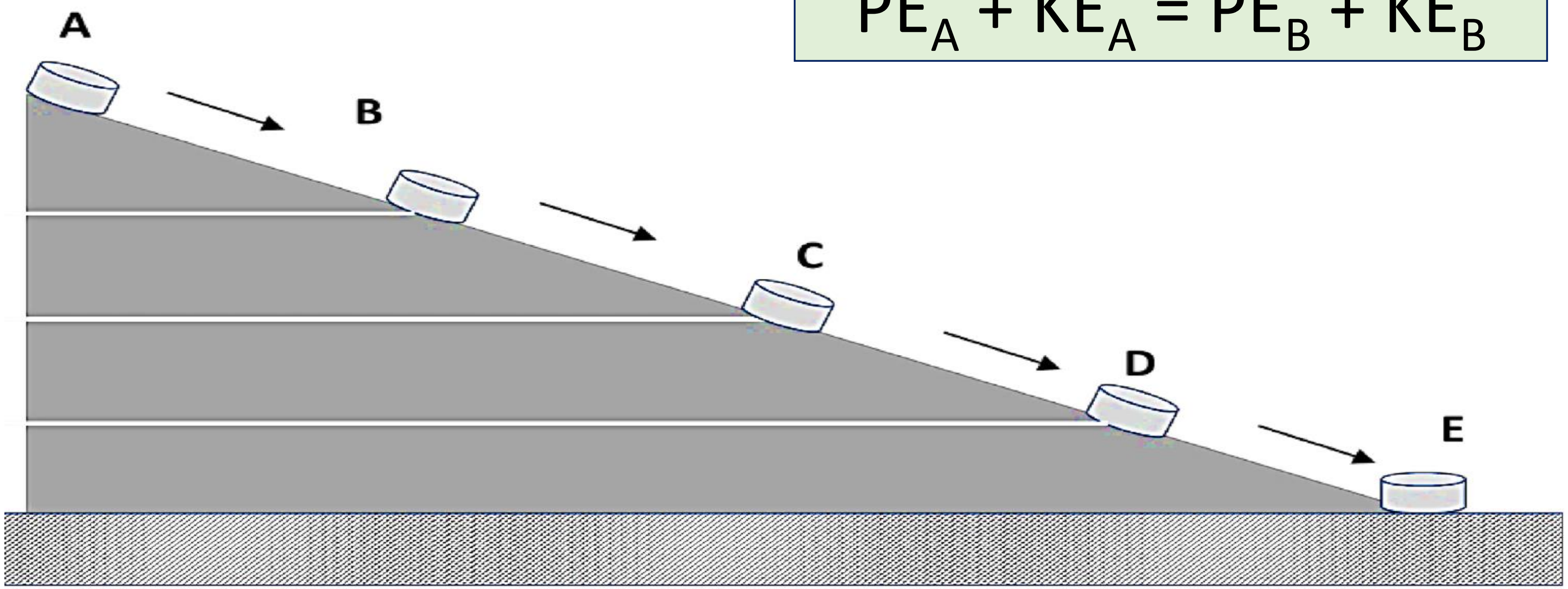
$$\frac{1}{2}(m_1 + m_2){v_B}^2 + 0 =$$
$$0 + (m_1 + m_2)gh$$

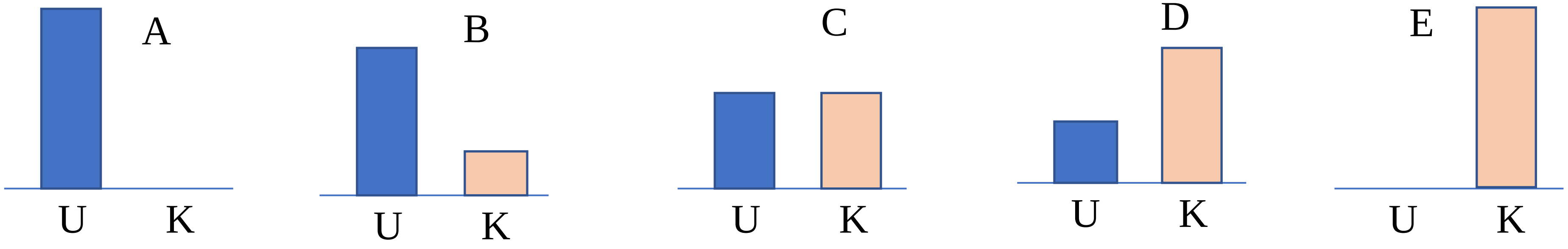
$$Putting\ the\ value\ of\ v_B \Rightarrow v_{1A} = \frac{(m_1 + m_2)}{m_1}\sqrt{2gh}$$

Conservation of Mechanical Energy – II

Slipping Object on Frictionless inclined surface

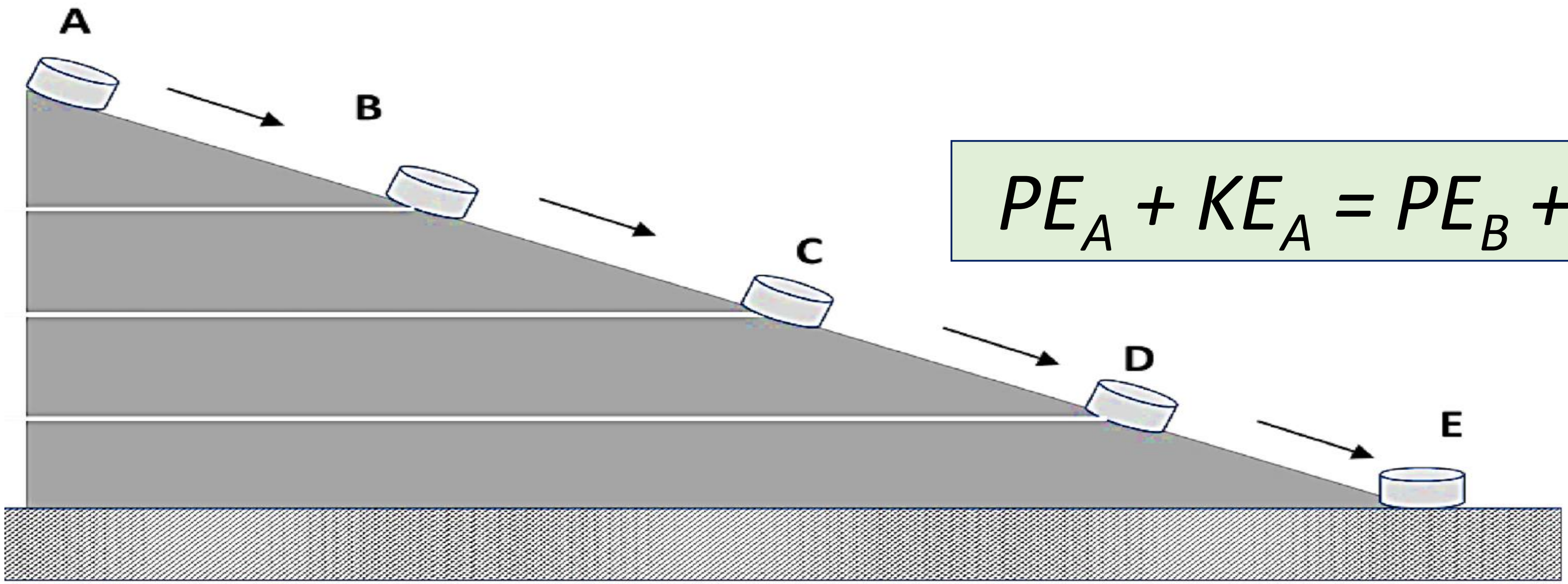
$$PE_A + KE_A = PE_B + KE_B$$





Conservation of Mechanical Energy – II

Slipping Object on Rough inclined surface



$$PE_A + KE_A = PE_B + KE_B + W_{Friction}$$

$$mgh_1 + 0 = mgh_2 + \frac{1}{2}mv^2 + \mu_k mg * cos\theta * (x_2 - x_1)$$

$$v^2 = 2g[(h_1 - h_2) - \mu_k cos\theta(x_2 - x_1)]$$

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

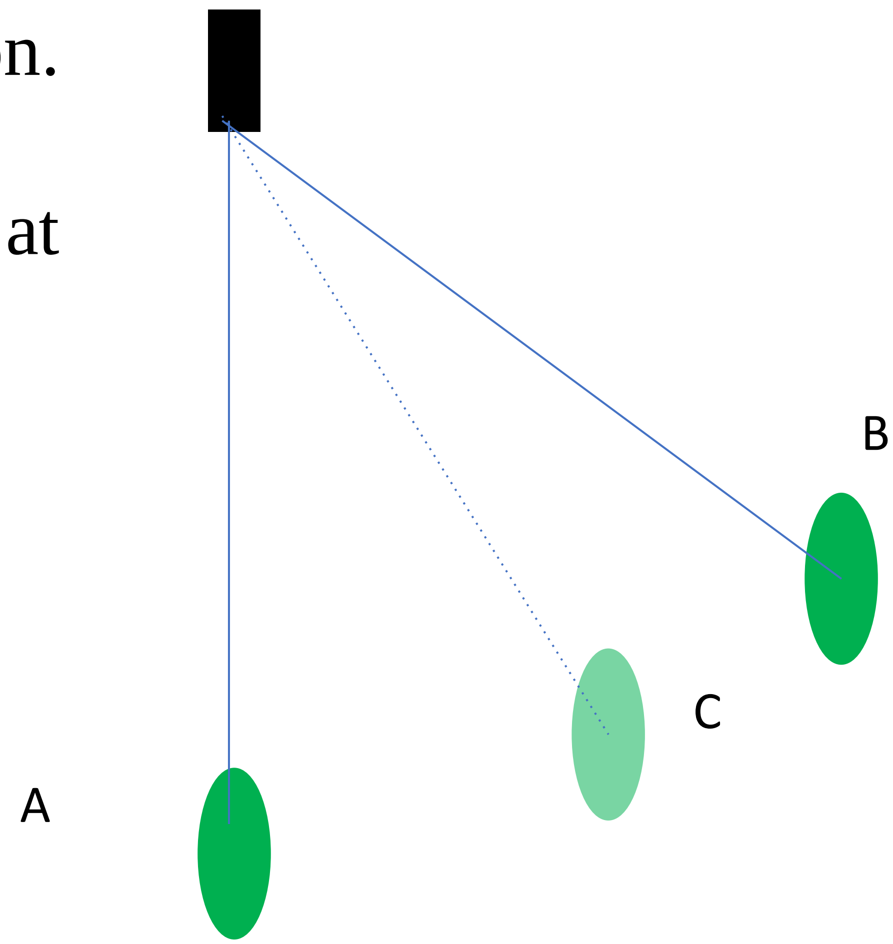
(a)What is the height the pendulum reaches at maximum position B w.r.t the lowest position?

A. 10m

B. 20m

C. 30m

D. 40m



Assume g=10m/s²