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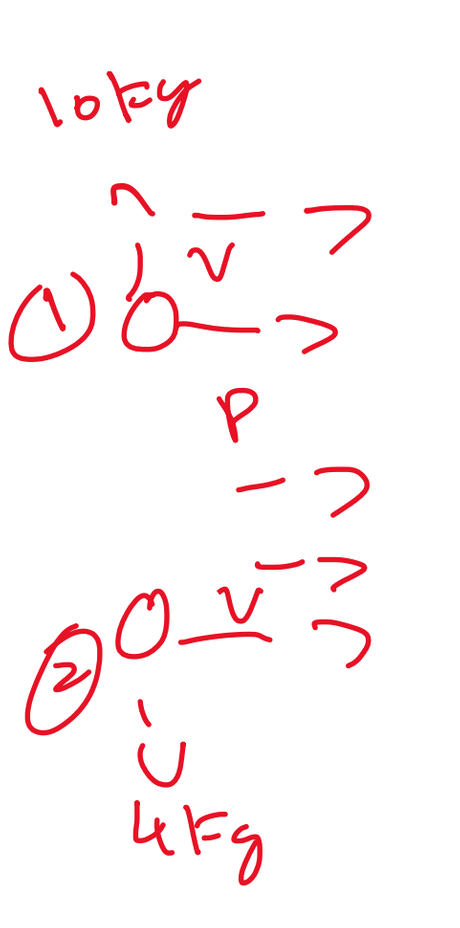
Momentum:

- Defined as the product of an object's mass and velocity. It is a vector quantity → has magnitude and direction

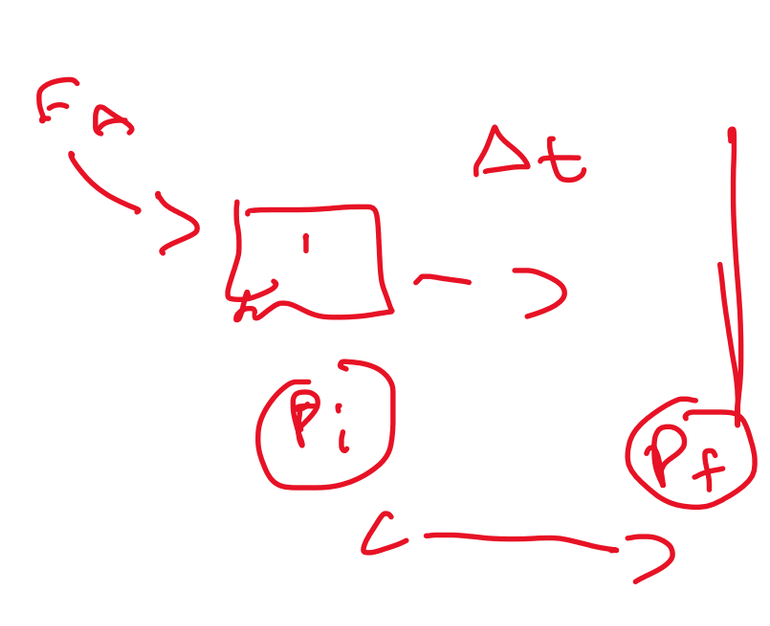
$P = m \cdot v$

- Units: SI unit of P is $kg \cdot (m/s)$ — $M \cdot V$, $kg \cdot m/s$
- Properties:
  - Direction of momentum is the same as the direction of the velocity of the object
  - Momentum increases with increase in mass/velocity
    - → i.e. Heavier object moving at same speed as a lighter has greater momentum



- Impulse and momentum:
  - Impulse (J): the change in momentum of an object when a force is applied over a period of time
    - Equal to product of average force applied and the time duration over which the force is applied

$\Delta P = J = F \Delta t$



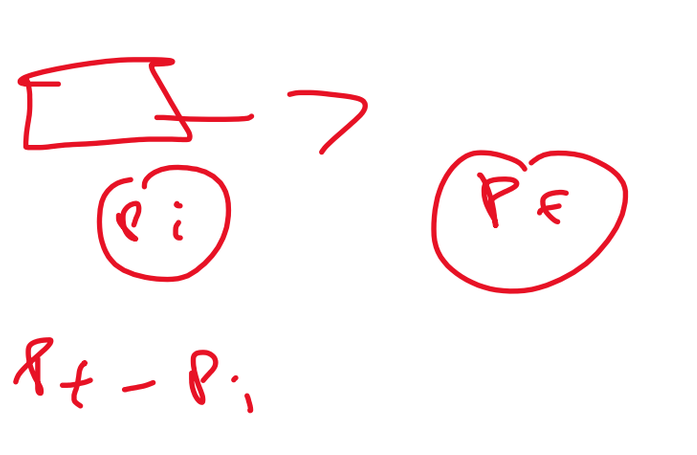
- Conservation of momentum:
  - In a closed system (no external forces acting on system), the total momentum before an event → collision is equal to the total momentum after

$P_i = P_f$

  - Applies to both elastic and inelastic collisions

- Impulse - momentum theory
  - States that the impulse applied to an object is equivalent to the change in its momentum

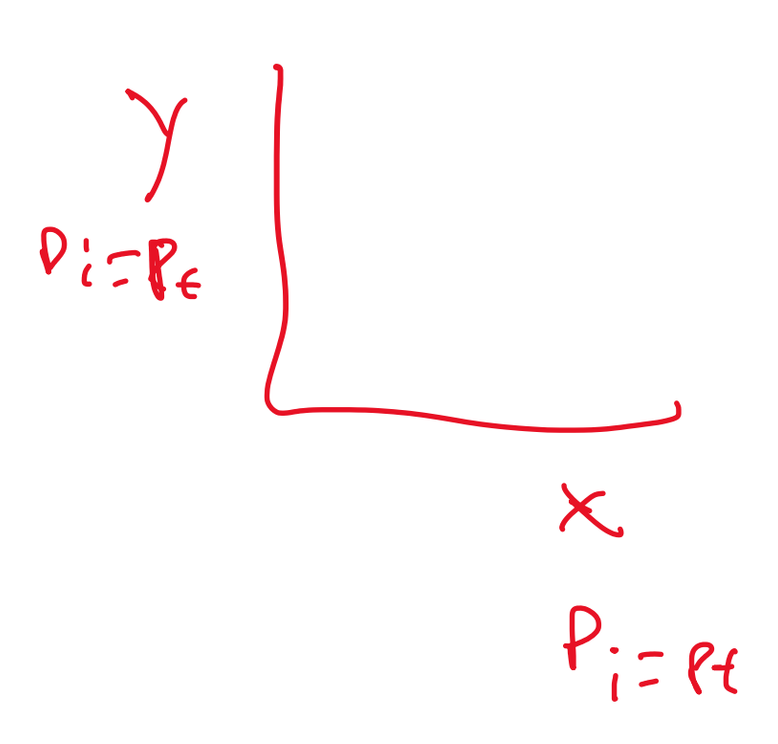
$J = \Delta P = P_f - P_i$



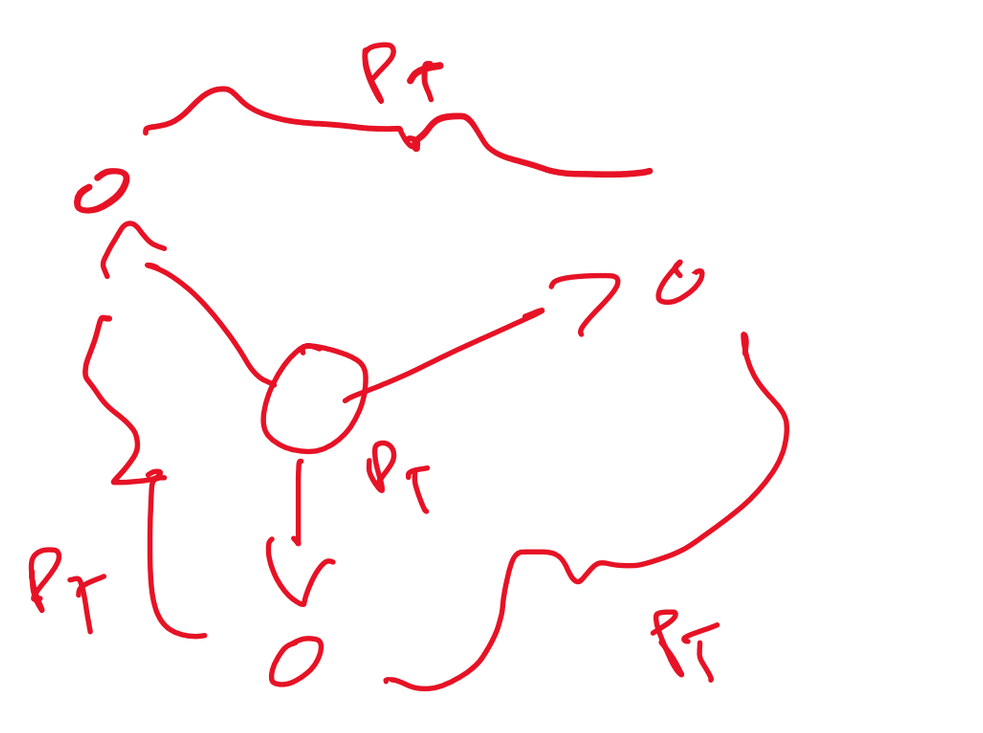
- Conservation of momentum in different scenarios:
  - Two-dimensional collisions: momentum must be conserved in both x and y directions. Requires breaking down momentum into components and applying laws seperately

$P_{xi} = P_{xf}$

$P_{yi} = P_{yf}$



  - Explosions: momentum is conserved. Total momentum before the explosion (when object is intact) is equal to the total momentum after the explosion (when the pieces are flying apart)



Examples:

① A 5kg object is initially at rest. A force of 20N is applied to the object for 3 seconds. Calculate impulse imparted to the object and final velocity.

Solution:

Givens:
- $F = 20N$
- $\Delta t = 3$ seconds
- $M = 5kg$
- $V_i = 0$ m/s

Unknowns:
- V_f ?
- J ?

Calculate impulse:

$J = F \Delta t$
$= 20(3)$
$= 60\ N \cdot s$

Calculate change in momentum:

$P = M \cdot V$

$J = \Delta P = P_f - P_i$

$J = P_f - P_i$

$J = P_f - 0$ ← $P_i = M V_i = M \cdot 0 = 0$

$J = M \cdot V - 0$

$60 = 5 V_f$

$V_f = 12\ m/s$

② A 3kg ball moving east at 4m/s collides with a 2kg ball at rest. After the collision, the 3kg ball moves at 2m/s at an angle of 30° North of East. Calculate final velocity of 2kg ball after the collision.

Solution:

Givens:
- $M_1 = 3kg$
- $v_{i1} = 4$ m/s [E]
- $M_2 = 2kg$
- $v_{i2} = 0$ m/s
- $V_{f1} = 2$ m/s [N 30 E]

Unknowns:
- P_i = ?
- P_f = ?
- V_{f2} = ?

Calculate momentum in the x:

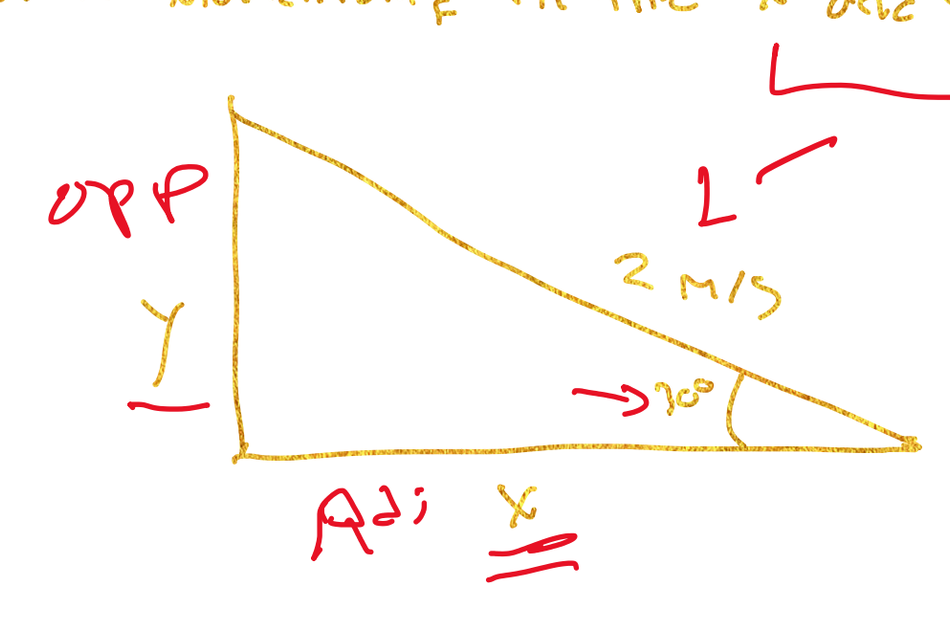
$P_{initial} = M_1 V_1 + M_2 V_2$

$P_i = 3(4) + 2(0)$

$P_i = 12\ kg\ m/s$

$P_{iy} = 0$

Calculate momentum$_f$ in the x and y:



SOH CAH TOA

$\cos\theta = \frac{adj}{hyp}$

$\sin\theta = \frac{opp}{hyp}$

V_{fx}: $\cos 30 = \frac{x}{2}$

$x = 2\cos 30$

$x = 1.732$ m/s

V_{fy}: $\sin 30 = \frac{y}{2}$

$y = 2\sin 30$

$y = 1$ m/s

x dir:

$P_{xi} = P_{fx}$

$12 = M_1 V_{1fx} + M_2 V_{2fx}$

$12 = 3(1.732) + 2 V_{2fx}$

$V_{2fx} = \frac{12 - 3(1.732)}{2}$

$V_{2fx} = 3.402$ m/s

y dir:

$P_{yi} = P_{yf}$

$0 = M_1 V_{1fy} + M_2 V_{2fy}$

$0 = 3(1) + 2V_{2fy}$

$2V_{fy} = 0 - 3$

$V_{fy} = \frac{0 - 3}{2}$

$V_{2fy} = -1.5$ m/s

Pythagorean theorum:

$a^2 + b^2 = c^2$

$V_{2fx}^2 + V_{2fy}^2 = V_{2f}^2$

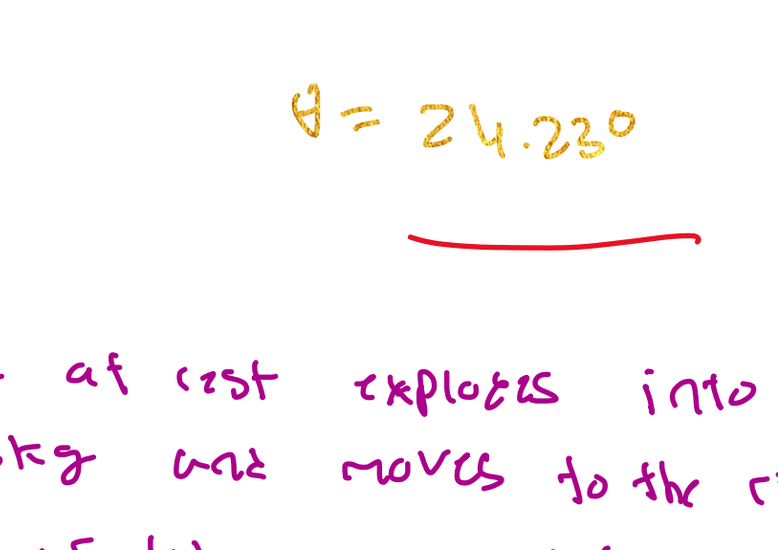
$3.402^2 + (-1.5)^2 = V_{2f}^2$

$V_{2f}^2 = 11.56 + 2.25$

$\sqrt{V_{2f}^2} = \sqrt{13.81}$

$V_{2f} = 3.71$ m/s

Calculate angle:



TOA

$\tan\theta = \frac{opp}{adj}$

$\tan\theta = \frac{1.5}{3.402}$

$\theta = \tan^{-1}(1.5/3.402)$ arctan

$\theta = 24.23°$

③ A 10kg object at rest explodes into 3 pieces. Piece A has a mass of 3kg and moves to the right at 6m/s. Piece B has a mass of 4kg and moves to the left at 3m/s. Calculate the velocity of piece C.

Solution:
- $M_0 = 10kg$
- $M_A = 3kg$ $V_A = 6$ m/s
- $M_B = 4kg$ $V_B = 3$ m/s
- $P_i = 0$

Unknowns:
- V_C = ?
- M_C = ?

Momentum of pieces of A and B:

Piece A:

$P_A = M_A V_A$
$= 3(6)$
$= 18\ kg \cdot m/s$

Piece B:

$P_B = M_B V_B$
$= 4(-3)$
$= -12\ kg \cdot m/s$

Total momentum after explosion:

$P_i = P_A + P_B + P_C$ → $P_i = P_f$

$0 = 18 - 12 + P_C$ → 0

$P_C = 0 - 18 + 12$
$= -18 + 12$
$= -6\ kg \cdot m/s$

Calculate M_C:

$M_0 = M_A + M_B + M_C$

$10 = 3 + 4 + M_C$

$10 = 7 + M_C$

$M_C = 10 - 7$
$= 3\ kg$

Calculate V_C: $P_C = M_C V_C$

$-6 = 3 V_C$

$V_C = -2$ m/s