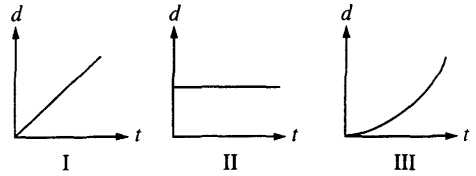
Momentum
- Related to both mass and velocity.
- Unlike energy, *momentum is a vector!*
- For one particle: $\mathbf{p} = m\mathbf{v}$
- For a system of multiple particles: $\mathbf{P} = \Sigma\mathbf{p}_i = \Sigma m_i\mathbf{v}_i$
- Units: kg m/s or N s

Problem: Momentum (1998)

Three objects can only move along a straight, level path. The graphs below show the position d of each of the objects plotted as a function of time t.



43. The magnitude of the momentum of the object is increasing in which of the cases?

(A) II only
(B) III only
(C) I and II only
(D) I and III only
(E) I, II, and III

Explain your reasoning:

Impulse (J)
- When there's a force for a period of time
- J = F t
- If the time is longer, the force is smaller
- If the time is shorter, the force is larger
- The area under a force *vs* time graph gives the impulse.

Impulse-momentum theorem
- An impulse changes an object's momentum.
- $J = \Delta p$
- Units: N s or kg m/s

Problem: Impulse (1998)

57. A ball of mass 0.4 kg is initially at rest on the ground. It is kicked and leaves the kicker's foot with a speed of 5.0 m/s in a direction 60° above the horizontal. The magnitude of the impulse imparted by the ball to the foot is most nearly

(A) $1\ \text{N}\cdot\text{s}$
(B) $\sqrt{3}\ \text{N}\cdot\text{s}$
(C) $2\ \text{N}\cdot\text{s}$
(D) $\frac{2}{\sqrt{3}}\ \text{N}\cdot\text{s}$
(E) $4\ \text{N}\cdot\text{s}$

Show your work:

Law of Conservation of Momentum
- The total momentum before a collision is equal to the total momentum after a collision
- $m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$
- Momentum is conserved in any collision, but KE may or may not be conserved.
  Elastic collision: KE is conserved
  Inelastic collision: KE is *not* conserved
  Perfectly inelastic collision: KE is *not* conserved and objects stick together
- Momentum conservation used for collisions and…
  → train cars linking, coupling, or locking
  → blocks sticking
  → a collision
  → a bullet being stopped/embedded or slowed by another object
  → a spring compressed between two masses and released
  → a single object exploding apart
  → someone or something landing on or falling off a sled

Problem: Collisions (1993)

10. Which of the following is true when an object of mass m moving on a horizontal frictionless surface hits and sticks to an object of mass M > m, which is initially at rest on the surface?

(A) The collision is elastic.
(B) All of the initial kinetic energy of the less-massive object is lost.
(C) The momentum of the objects that are stuck together has a smaller magnitude than the initial momentum of the less-massive object.
(D) The speed of the objects that are stuck together will be less than the initial speed of the less-massive object.
(E) The direction of motion of the objects that are stuck together depends on whether the hit is a head-on collision.

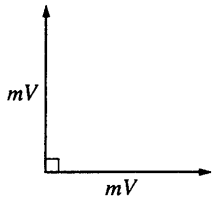
Explain your reasoning:

Problem: Collisions (1984)

2. A railroad flatcar of mass 2,000 kilograms rolls to the right at 10 meters per second and collides with a flatcar of mass 3,000 kilograms that is rolling to the left at 5 meters per second. The flatcars couple together. Their speed after the collision is
(A) 1 m/s
(B) 2.5 m/ s
(C) 5 m/ s
(D) 7 m/ s
(E) 7.5 m/ s

2D momentum problems
Separate the problem into two 1 dimensional problems/
Momentum is conserved in each dimension/

Problem: Explosion (1998)



67. A stationary object explodes, breaking into three pieces of masses m, m, and $3m$. The two pieces of mass m move off at right angles to each other with the same magnitude of momentum mV, as shown in the diagram above. What are the magnitude and direction of the velocity of the piece having mass $3m$?

	Magnitude	Direction
(A)	$\frac{V}{\sqrt{3}}$	↗
(B)	$\frac{V}{\sqrt{3}}$	↙
(C)	$\frac{\sqrt{2}\,V}{3}$	↗
(D)	$\frac{\sqrt{2}\,V}{3}$	↙
(E)	$\sqrt{2}\,V$	↙

Show your work: