Hewitt/Lyons/Suchocki/Yeh

Conceptual Integrated Science

Chapter 4

MOMENTUM AND ENERGY

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Momentum

Momentum—is *inertia in motion*

defined as the product of mass and velocity:

momentum: $p = mv$

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Momentum

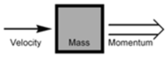
Momentum = mass × velocity

or

Momentum = mass × speed (*when direction is unimportant*)

Momentum = mv

UNITS = kg x m/s = kg-m/s



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Momentum

high mass or high velocity ⇒ high momentum

high mass and high velocity ⇒ higher momentum

low mass or low velocity ⇒ low momentum

low mass and low velocity ⇒ lower momentum

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Momentum

Which object has more momentum?

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Impulse

Impulse—the product of force and contact time.

Equation for impulse:

Impulse = force × time = Ft (UNITS = N-s)

great force for long time ⇒ large impulse

same force for short time ⇒ smaller impulse

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Impulse–Momentum Relationship

The change in momentum of an object is equal to the force applied to it multiplied by the time interval during which the force is applied.

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Impulse–Momentum Relationship

Equation:

Impulse = change in momentum
or
Force × time = Δ momentum ($Ft = \Delta p$)

greater force, greater change in velocity ⇒ greater change in momentum

same force for short time ⇒ smaller change in momentum

same force for longer time ⇒ more change in momentum

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Impulse–Momentum Relationship

Cases of momentum changes:

Increasing Momentum

Apply the greatest force for the longest time to produce the maximum increase in momentum

Examples:

- Long-range cannons have long barrels for maximum range
- A golfer follows through while teeing off

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Impulse–Momentum Relationship

Cases of momentum changes:

Decreasing Momentum

The impulse with the longer time that decreases momentum has a smaller force.

Examples:

- Driving into a haystack versus a brick wall
- Jumping into a safety net versus onto solid ground

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Conservation of Momentum

In every case, the momentum of a system cannot change unless it is acted on by external forces.

A system will have the same momentum both before and after the interaction occurs. When the momentum does not change, we say it is **conserved**.

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Conservation of Momentum

Law of conservation of momentum:

In the absence of an external force, the momentum of a system remains unchanged.

Equation form:

$(\text{total momentum})_{\text{before}} = (\text{total momentum})_{\text{after}}$

$$p_{\text{before}} = p_{\text{after}}$$

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Conservation of Momentum

Collisions

When objects collide in the absence of external forces,

net momentum before collision = net momentum after collision

Examples:

Elastic collisions

Inelastic collisions

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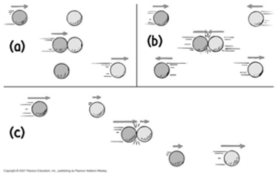
Conservation of Momentum

Elastic collision

is defined as a collision whereupon objects collide without permanent deformation or the generation of heat.



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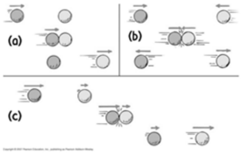
Conservation of Momentum

Case A:

Moving Ball A strikes Ball B, initially at rest.

Ball A comes to rest, and Ball B moves away with a velocity equal to the initial velocity of Ball A.

Momentum is transferred from Ball A to Ball B.



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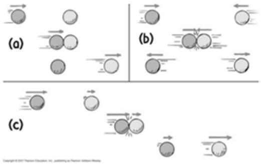
Conservation of Momentum

Case B:

Moving Ball A strikes Ball B, moving at the same speed in the opposite direction.

Ball A and Ball B move away with a velocity equal to their initial velocities. Momentum is transferred between the two balls.



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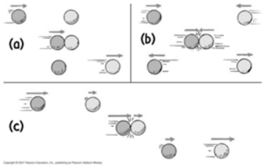
Conservation of Momentum

Case C:

Moving Ball A strikes Ball B, with Ball A moving at a greater speed than Ball B in the same direction.

Ball A and Ball B move away with new velocities equal to their initial velocities. Momentum is transferred between the two balls.



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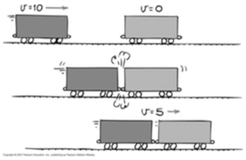
Conservation of Momentum

Inelastic collision

is defined as a collision whereupon colliding objects become tangled or coupled together, generating heat. Momentum is still conserved.



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Work

Work is defined as the product of force exerted on an object and the distance the object moves (in the same direction as the force).

Work is done only when a force succeeds in displacing the body it acts upon.

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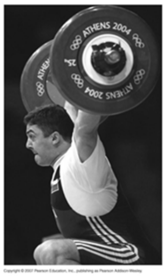
Work



Two things enter where work is done:
- application of force
- movement of something by that force

Work done on the object is the average force multiplied by the distance through which the object is moved.

W = F x d (UNITS = N-m)

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Work

The quantity of work done is equal to the amount of force × the distance moved in the direction in which the force acts.

Work falls into two categories:
- work done against another force
- work done to change the speed of an object

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Energy

Energy is defined as that which produces changes in matter.

The effects of energy are observed only when it is being transferred from one place to another

or

transformed from one form to another.

Unit for energy: the Joule (J) or N-m

Both work and energy are measured in *Joules*.

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Power

Power

is a measure of how quickly work is done

or

the rate at which energy is changed from one form to another.

Equation for power:

$$\text{Power} = \frac{\text{work done}}{\text{time interval}}$$

Units for power: joule per second (J/s), or Watt (W)

(One Watt = 1 Joule of work per second)

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Potential Energy

Potential Energy

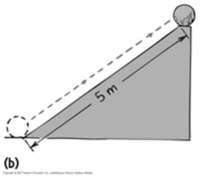
is defined as stored energy due to position, shape, or state. In its stored state, energy has the potential for doing work.

Examples:

Drawn bow

Stretched rubber band

Rolling a ball up a ramp



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Potential Energy

The amount of gravitational potential energy possessed by an elevated object is equal to the work done against gravity in raising it.

Work done equals force required to move it upward × the vertical distance moved ($W = Fd$).

The upward force when moved at constant velocity is the weight, mg, of the object. So the work done in lifting it through height h is the product mgh.

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Potential Energy

Equation for gravitational potential energy:

PE = weight × height

or

$PE = mgh$

Gravitational potential energy examples:

Water in an elevated reservoir

The elevated ram of a pile driver

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Kinetic Energy

Kinetic Energy

is defined as the energy of a moving body

Equation for kinetic energy:

Kinetic energy = $^1/_2$ mass × velocity^2

or

Kinetic energy = $^1/_2\, mv^2$

small changes in speed ⇒ large **changes** in kinetic energy

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The Work-Energy Theorem

When work is done on an object to change its kinetic energy, the amount of work done is equal to the change in kinetic energy.

Equation for work-energy theorem:

Net work = change in kinetic energy

$\text{Work}_{\text{Net}} = \Delta KE$

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The Work-Energy Theorem

$\text{Work}_{\text{Net}} = \Delta KE + \Delta PE$

- If there is no change in object's energy, then no work is done.
- Applies to potential energy: For a barbell held stationary, no further work is done ⇒ no further change in energy
- Applies to decreasing energy:

  The more kinetic energy something has ⇒ the more work is required to stop it

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Kinetic Energy and Momentum

Comparison of Kinetic Energy and Momentum

- Both depend on mass and velocity—

  Momentum depends on mass and velocity.

  KE depends on mass and the *square* of its velocity.
- Momentum is a vector quantity.

  Kinetic energy is a scalar quantity.

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Conservation of Energy

Conservation

is defined in everyday language as “to save”—in physics, to “remain unchanged.”

Law of conservation of energy:

In the absence of external work input or output, the energy of a system remains unchanged. “Energy cannot be created or destroyed.”

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Conservation of Energy
A situation to ponder…

Consider the system of a bow and arrow. In drawing the bow, we do work on the system and give it potential energy. When the bowstring is released, most of the potential energy is transferred to the arrow as kinetic energy and some as heat to the bow.

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Suppose the potential energy of a drawn bow is 50 joules, and the kinetic energy of the shot arrow is 40 joules. Then

✗ A. energy is not conserved.
✓ B. 10 joules go to warming the bow.
✗ C. 10 joules go to warming the target.
✗ D. 10 joules is mysteriously missing.

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Machines

Machine—a device for multiplying force or changing the direction of force.

No machine can
- put out more energy than is put into it.
- create energy; it can only transfer or transform energy.

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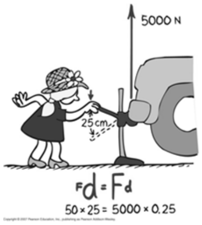
Machines

Example: The Lever



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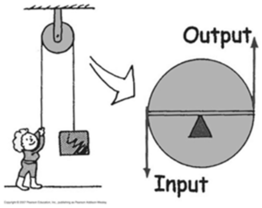
Machines

Example: The Pulley



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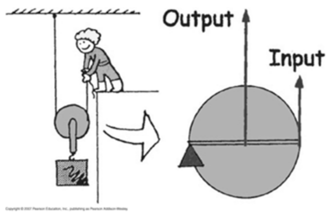
Machines

Example: The Pulley



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Machines

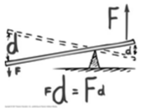
Equation:

work input = work output

(force × distance)$_{\text{input}}$ = (force × distance)$_{\text{output}}$

Example: a simple lever

small input force over a long distance ⇒ large output force over a short distance



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Efficiency

Efficiency—how effective a device transforms or transfers useful energy.

Equation for efficiency:

$$\text{Efficiency} = \frac{\text{work done}}{\text{energy used}} \times 100\%$$

a machine with low efficiency ⇒ greater amount of energy wasted as heat

Some energy is always dissipated as heat, which means that no machine is ever 100% efficient.

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