Conceptual Physics Fundamentals

Chapter 5:
MOMENTUM AND ENERGY
This lecture will help you understand:

- Momentum
- Impulse
- Impulse Changes Momentum
- Bouncing
- Conservation of Momentum
- Collisions
- Energy
- Work
- Potential Energy
- Work-Energy Theorem
- Conservation of Energy
- Power
- Machines
- Efficiency
- Sources of Energy
Momentum and Energy

“Human history becomes more and more a race between education and catastrophe.”

—H. G. Wells
Momentum

Momentum

• a property of moving things
• means inertia in motion
• more specifically, mass of an object multiplied by its velocity
• in equation form: mass \times velocity

(momentum = mv)
MOMENTUM
What is momentum?

*Inertia in Motion.*

\[ p = mv \]

How hard something is to stop.
Impulse Changes Momentum

The greater the impulse exerted on something, the greater the change in momentum.

• in equation form: $Ft = \Delta(mv)$
Stop it!
Hay stack or Concrete Wall?
Stop it!

Hay stack or Concrete Wall?

\[ \Delta p = F \Delta t = F \Delta t \]
Impulse: Change in Momentum

\[ \Delta p = F \Delta t \]
Million Dollar Baby!

Same Impulse, different Force and Time.

\[ F \int = \text{change in momentum} \]

(a)

\[ F \int = \text{change in momentum} \]

(b)
In Sum…

**Momentum:** Inertia in Motion.

\[ p = mv \]

**Impulse:** Change in Momentum

\[ \Delta p = F \Delta t \]
When the force that produces an impulse acts for twice as much time, the impulse is

A. not changed.
B. doubled.
C. quadrupled.
D. halved.
When the force that produces an impulse acts for twice as much time, the impulse is

A. not changed.
B. doubled.
C. quadrupled.
D. halved.
The recoil momentum of a gun that kicks is more than less than the same as the momentum of the bullet it fires.

Gun pushes bullet, bullet pushes gun!

Since no outside forces act on the gun + man system the total momentum before and after is constant. This is called Conservation of Momentum.

Little mass, high speed: \( p = mV \)
Is the same as big mass, low speed: \( p = Mv \)
Rocket Thrust
Momentum is Conserved

Rocket Pushes Gas Out: $p = mV$
Gas Pushes Back on Rocket: $p = Mv$
Conservation of Momentum

If there are no external forces acting on a system of objects then the total momentum before an event is equal to the total momentum after an event.

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

The mass of the big fish is 4X the mass of the little fish.

Speed of Small Fish = 5 km/hr
Conservation of Momentum

Granny (m=80kg) whizzes around the rink at 3m/s and snatches up Andy (m=40kg). What is their final velocity? (Ignore friction)
Conservation of Momentum

Practice Book page 32

What is the system?

\[ \sum p_{\text{initial}} = \sum p_{\text{final}} \]

Granny: \( m=80\text{kg}, \ v_0=3\text{m/s} \)

Andy: \( m=40\text{kg}, \ v_0=0 \)

Before

After
Conservation of Momentum

Momentum is conserved for which system?

 INCLUDE EVERYTHING THAT GOES BUMP!

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NOTICE HOW THE INTERNAL FORCES CANCEL!
Collisions in Lab Next Week

Total momentum before = Total momentum after
**Main Ideas**

*(Encyclopedia of Physics)*

*Energy* is an abstract quantity that an object is said to possess. It is not something you can directly observe. The usefulness of the concept comes from the Conservation of Energy. In predicting the behavior of objects, one uses the Conservation of Energy to keep track of the total energy and the interchange of energy between its various forms and between objects.

*Work* is the transfer of energy from one object to another by a force from one on the other that displaces the other.

*Power* is the rate at which energy is transferred or, the rate at which work is done. Power is the *FLOW* of energy.
Units

Energy & Work are scalars and have units of the Joule:

\[ W = Fd \rightarrow N \cdot m = kg \cdot \frac{m^2}{s^2} = J \]

\[ PE = mgh \rightarrow kg \cdot \frac{m}{s^2} \cdot m = kg \cdot \frac{m^2}{s^2} = J \]

\[ KE = \frac{1}{2}mv^2 \rightarrow kg \left(\frac{m}{s}\right)^2 = kg \cdot \frac{m^2}{s^2} = J \]
<table>
<thead>
<tr>
<th>Object/phenomenon</th>
<th>Energy in joules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big bang</td>
<td>$10^{68}$</td>
</tr>
<tr>
<td>Energy released in a supernova</td>
<td>$10^{44}$</td>
</tr>
<tr>
<td>Hydrogen fusion energy in the oceans</td>
<td>$10^{36}$</td>
</tr>
<tr>
<td>Annual U.S. energy use</td>
<td>$8 \times 10^{19}$</td>
</tr>
<tr>
<td>Large fusion bomb (9 megaton)</td>
<td>$3.8 \times 10^{16}$</td>
</tr>
<tr>
<td>1 kg hydrogen (fusion to helium)</td>
<td>$6.4 \times 10^{14}$</td>
</tr>
<tr>
<td>1 kg uranium (nuclear fission)</td>
<td>$8.0 \times 10^{13}$</td>
</tr>
<tr>
<td>Hiroshima-size fission bomb (10 kiloton)</td>
<td>$4.2 \times 10^{13}$</td>
</tr>
<tr>
<td>90,000 ton aircraft carrier at 30 knots</td>
<td>$1.1 \times 10^{10}$</td>
</tr>
<tr>
<td>1 barrel crude oil</td>
<td>$5.9 \times 10^{9}$</td>
</tr>
<tr>
<td>1 ton TNT</td>
<td>$4.2 \times 10^{9}$</td>
</tr>
<tr>
<td>1 gallon gasoline</td>
<td>$1.3 \times 10^{8}$</td>
</tr>
<tr>
<td>Daily adult food intake</td>
<td>$1.2 \times 10^{7}$</td>
</tr>
<tr>
<td>1 ton car at 90 km/h</td>
<td>$3.1 \times 10^{5}$</td>
</tr>
<tr>
<td>1 g fat (9.3 kcal)</td>
<td>$3.9 \times 10^{4}$</td>
</tr>
<tr>
<td>1 g carbohydrate (4.1 kcal)</td>
<td>$1.7 \times 10^{4}$</td>
</tr>
<tr>
<td>1 g protein (4.1 kcal)</td>
<td>$1.7 \times 10^{4}$</td>
</tr>
<tr>
<td>Baseball at 100 mph</td>
<td>$1.5 \times 10^{2}$</td>
</tr>
<tr>
<td>Mosquito ($10^{-2}$ g) at 0.5 m/s</td>
<td>$1.3 \times 10^{-6}$</td>
</tr>
<tr>
<td>Single electron in a TV tube</td>
<td>$4.0 \times 10^{-15}$</td>
</tr>
<tr>
<td>Single electron in 120 V line</td>
<td>$1.9 \times 10^{-17}$</td>
</tr>
<tr>
<td>Energy to break one DNA strand</td>
<td>$10^{-19}$</td>
</tr>
</tbody>
</table>
Sources & Cycles of Energy

- Solar Energy
  - Power
  - Fossil Fuels
  - Plants
  - Food
  - Animals
Power: Sources of Energy
Tidal Power

SF Bay Tidal Power Project
Conservation of Energy

Energy can neither be created nor destroyed. It may change in form or be transferred from one system to another.

The total amount of energy in the Universe is constant and can never change.

\[ E_i = E_f \]

Except for VERY brief amounts of time according to the Heisenberg Uncertainty Principle.
Ways to Transfer Energy Into or Out of A System

- **Work** – transfers by applying a force and causing a displacement of the point of application of the force

- **Mechanical Waves** – allow a disturbance to propagate through a medium

- **Heat** – is driven by a temperature difference between two regions in space
More Ways to Transfer Energy Into or Out of A System

• **Matter Transfer** – matter physically crosses the boundary of the system, carrying energy with it

• **Electrical Transmission** – transfer is by electric current

• **Electromagnetic Radiation** – energy is transferred by electromagnetic waves
Energy

The ability to do work.

The ability to apply forces across distances.
Work

A force applied across a distance.

\[ W = \text{Force} \times \text{Distance} = Fd \]
Kinetic Energy

The energy an object has due to its motion.

\[ KE = \frac{1}{2}mv^2 \]
Energy

Left to their own device, systems always seek out the lowest energy state available to them. Systems want to be at rest or in a constant state of motion.

You have to do work on the Rock to roll it back up the hill. This will give the Rock Energy – the potential of rolling back down – **Potential Energy**.
Potential Energy

The energy an object has due to its position in a force field. For example: gravity or electricity. The Potential Energy is relative to a ‘ground’ that is defined.

The “ground”: $h = 0$
Gravitational Potential Energy

\[ PE = mgh \]

It takes work to move the object and that gives it energy!

IMPORTANT!
Either path gives the same potential energy!
WHY?

Same change in height!

\[ PE = mgh \]
Gravitational Potential Energy

Which ball has the greatest potential energy?

SAME!

Same height – Same Potential Energy!
Gravitational Potential Energy

The block of ice weighs 500 Newtons. How much work does it take to push it up the incline compared to lifting it straight up? Ignore friction.

(Practice Book 35)
Gravitational Potential Energy

\[ \text{Work} = \text{Force} \times \text{Distance} \]

Straight up: \[ W = Fd = 500N \times 3m = 1500J \]

Push up: \[ F = ? \quad W = Fd = 1500J \]
\[ F = \frac{W}{d} = \frac{1500J}{6m} = 250N \] \quad \text{Half the Weight!} 

What is the PE at the top?

\[ mg = 500N \]

An incline is a simple machine!
Work-Energy Theorem \( W = \Delta KE \)

Work-energy theorem

- gain or reduction of energy is the result of work
- in equation form: work = change in kinetic energy \( (W = \Delta KE) \)
- doubling speed of an object requires 4 times the work
- also applies to changes in potential energy
Traveling at 70 miles per hour, what is your breaking distance?

\[ W_{\text{Net}} = \Delta KE \quad \Rightarrow \quad F \Delta r = \frac{1}{2} mv^2 \]

\[ \Delta r = \frac{1}{2} \frac{mv^2}{F} = \frac{1}{2} \frac{mv^2}{ma} = \frac{v^2}{2a} \]

If \( v \) doubles, \( \Delta r \) quadruples!!!
Consider a problem that asks for the distance of a fast-moving crate sliding across a factory floor and then coming to a stop. The most useful equation for solving this problem is

A. \( F = ma. \)
B. \( Ft = \Delta mv. \)
C. \( KE = \frac{1}{2}mv^2. \)
D. \( Fd = \Delta \frac{1}{2}mv^2. \)
Consider a problem that asks for the distance of a fast-moving crate sliding across a factory floor and then coming to a stop. The most useful equation for solving this problem is

A. $F = ma.$
B. $Ft = \Delta mv$
C. $KE = \frac{1}{2}mv^2.$
D. $Fd = \Delta \frac{1}{2}mv^2.$

Comment:
The work-energy theorem is the physicist’s favorite starting point for solving many motion-related problems.
The work done in bringing a moving car to a stop is the force of tire friction \( \times \) stopping distance. If the initial speed of the car is doubled, the stopping distance is

A. actually less.
B. about the same.
C. twice.
D. four times.
The work done in bringing a moving car to a stop is the force of tire friction \( \times \) stopping distance. If the initial speed of the car is doubled, the stopping distance is

A. actually less.
B. about the same.
C. twice.
D. four times.

Explanation:
Twice the speed means four times the kinetic energy and four times the stopping distance. 

\[ Fd = \Delta 1/2mv^2. \]
Conservation of Energy

Frictionless Ramp

\[ E_i = E_f \]

\[ KE_i + PE_i = KE_f + PE_f \]

(Practice Book 37)
Simple Machines

**Force Multipliers**

\[ F_d = F_d \]

Same Work, Different Force, Different Distance
Simple Machines

Which way takes less applied Force to lift the box?
Which takes less work?

Assume the Pulley has negligible mass.
Machines

- pulley
  - operates like a lever with equal arms—changes the direction of the input force
Machines

example:
this pulley arrangement can allow a load to be lifted with half the input force

• operates as a system of pulleys (block and tackle)
• multiplies force

(Practice Book 38)
In an ideal pulley system, a woman lifts a 100-N crate by pulling a rope downward with a force of 25 N. For every 1-meter length of rope she pulls downward, the crate rises

A. 50 centimeters.
B. 45 centimeters.
C. 25 centimeters.
D. none of the above
In an ideal pulley system, a woman lifts a 100-N crate by pulling a rope downward with a force of 25 N. For every 1-meter length of rope she pulls downward, the crate rises

A. 50 centimeters.
B. 45 centimeters.
C. **25 centimeters.**
D. none of the above

Explanation:
Work in = work out; $Fd_{in} = Fd_{out}$.
One-fourth of 1 m = 25 cm.
Conservation of Energy

If there are no frictional forces, PE is converted into KE.

Potential energy → Potential + kinetic → Kinetic energy → Potential energy
And so on
Three baseballs are thrown from the top of the cliff along paths A, B and C. If their initial speeds are the same and there is no air resistance, the ball that strikes the ground below with the greatest speed will follow path

a) A  b) B  c) C  d) either A or C  e) all strike with the same speed
Power

• measure of how fast work is done
• in equation form:

\[ Power = \frac{work\ done}{time\ interval} \]
Units

\[ P = \frac{Work}{time} \]

Power has a unit of a Watt: \( Watt = \frac{J}{s} \)

Energy in terms of Power is

\[ Energy = Power \cdot Time \]

For example, Kilowatt-hour
Power

example:

• A worker uses more power running up the stairs than climbing the same stairs slowly.

• Twice the power of an engine can do twice the work of one engine in the same amount of time, or twice the work of one engine in half the time or at a rate at which energy is changed from one *form* to another.
Power

Unit of power
— joule per second, called the watt after James Watt, developer of the steam engine

• 1 joule/second = 1 watt
• 1 kilowatt = 1000 watts
Machines

Machine

• device for multiplying forces or changing the direction of forces

• cannot create energy but can transform energy from one form to another, or transfer energy from one location to another

• cannot multiply work or energy
Machines

Principle of a machine

• conservation of energy concept:
  \[ \text{work input} = \text{work output} \]

• input force \( \times \) input distance = output force \( \times \) output distance

• \((\text{force} \times \text{distance})_{\text{input}} = (\text{force} \times \text{distance})_{\text{output}}\)
Machines

Simplest machine

• lever
  – rotates on a point of support called the fulcrum
  – allows small force over a large distance and large force over a short distance
Car Crash Video!
Types of Collisions

Momentum is conserved for all Collisions. Momentum is transferred during Collisions.

**Perfectly Elastic:** The total Kinetic Energy of the system is conserved. *Think Bounce!*

**Inelastic:** The total Kinetic Energy of the system is not conserved.

**Perfectly Inelastic:** The total Kinetic Energy is not conserved. *Think Stick!*

Why is momentum conserved during Inelastic Collisions but kinetic energy is not?
Elastic Collisions: *Bounce*

Momentum is transferred!

Total momentum before = Total momentum after
Inelastic Collisions: *Stick*

Total momentum before = Total momentum after
Inelastic Collisions: *Stick*

Was Momentum Conserved in this case?

*Momentum is always Conserved!*
<table>
<thead>
<tr>
<th></th>
<th>Truck</th>
<th></th>
<th>Car</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass (kg)</td>
<td>3000</td>
<td>-------</td>
<td>1000</td>
</tr>
<tr>
<td>vel. (m/s)</td>
<td>20.0</td>
<td>-------</td>
<td>0.0</td>
</tr>
<tr>
<td>mom. (kg m/s)</td>
<td>60 000</td>
<td>-------</td>
<td>0</td>
</tr>
</tbody>
</table>

Diagram:
- A large truck labeled "MOMENTUM TRANSFER" is on the left.
- A small car is on the right.

Diagram:
- Same as above.
<table>
<thead>
<tr>
<th>Car</th>
<th>Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass (kg)</td>
<td>1000</td>
</tr>
<tr>
<td>vel. (m/s)</td>
<td>20.0</td>
</tr>
<tr>
<td>mom. (kg m/s)</td>
<td>20 000</td>
</tr>
</tbody>
</table>
Collision Decision

Both trucks have the same speed and mass. In our simple physics world, what is NOT allowed:

a) Bounce off each other  **Elastic**
b) Stick and move to the left  **Impossible**
c) Stick and move to the right  **Impossible**
d) Stick and stop dead in the center  **Inelastic**
e) Vaporize  **Matter-Antimatter trucks!**
Conservation of Momentum