Physics Around Us
Dr. Andrew Robinson
Lecture 2
Power, Energy and Temperature

From Last Class
• Hummingbirds
• How they hover. Figure of 8 wing motion.
• https://www.youtube.com/watch?v=FPRswRWZ23Q&feature=youtu.be
• At the 2.54 minute marks

Torque
• When an object rotates, a force must be applied at a distance from the axis of rotation
• This is the torque

\[ \text{torque} = \text{distance} \times \text{force} \]

• If the torque and displacement vectors are at right angles

• The same force gives a bigger torque, if it is further from the axis of rotation

• Balances work by having torques applied to each side. If the torques exactly cancel, the balance remains at equilibrium

• Hold the wrench at point B to generate a larger torque
• Use a longer wrench
Equal torques but in opposite directions: equilibrium

Centre of Mass/Gravity

- The Centre of Mass (or Centre of Gravity) is the point at which the force of gravity acts.
- Usually this is in the centre of the object

If the Centre of Mass is not centred, then there is a torque acting which tends to tilt the object

Objects moving around each other orbit a common centre of mass

- This is closer to the more massive object

Energy

Generating Energy
Energy: A Property of Everything

• A property of a system which gives it the capacity to move
• A property which defines the temperature of a substance
• Things that aren’t moving can have energy too!
• Things that you can’t see (fields) can have energy

https://cosmosmagazine.com/physics/what-is-energy

Law of Conservation of Energy

• The total amount of energy in the universe is constant.
• It cannot be created or destroyed
• It may be converted into other forms of energy

Kinetic Energy

• Things moving

\[ K = \frac{1}{2} m v^2 \]

• Depends on the mass m
• Depends on the square of the speed

Rotational Kinetic Energy

• A rotating object also has kinetic energy

Rolling Object

• Has both rotational kinetic energy AND translational kinetic energy

Rest Mass

• The Einstein Equation

\[ E = mc^2 \]

• Everything that has mass, has an associated rest energy.
• Sometimes, some of the mass can be turned into energy (nuclear reactions)
Potential Energy

- Things have potential energy if they are in a gravitational field
- The greater the distance from the centre of the earth, the more gravitational potential energy

Electrical Potential Energy

- High Electrical Potential Energy
- Low Electrical Potential Energy

The volt (electrical potential, voltage) is proportional to the electrical potential energy

Energy Stored in Fields

- Energy can be stored in electric and magnetic fields
- Energy can be transmitted from place to place by using moving electric (E) and magnetic fields (B) (electromagnetic radiation)
- Light, radio etc

Heat Energy of Substances

- Heat energy is measured by the temperature
- Heat energy is energy of motion.
- Gases and liquids

Kinetic energy within the molecule
Random motion of the atoms and molecules

Thermal motion within solid materials
Atoms oscillate around a fixed position
There are lots of possible oscillations!

https://www.youtube.com/watch?v=_vtSurlZKcg&feature=youtu.be
Units of Energy

- The Joule
- Kilojoule (kJ) and Megajoule (MJ) are often used

James Prescott Joule 1818 - 1889

Joule was a brewer, and was interested in replacing steam engines in the brewery with electric motors

Statue in Manchester Town Hall

The Calorie

- Sometimes called the “Food Calorie”
- Used in nutrition

The heat energy to warm up one kilogram of water by 1°C

The British Thermal Unit

- The British thermal unit (Btu or BTU)
- Defined as the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

Not used by the British!
Used in the US
Used in Canada for heaters, air conditioners etc.

The Calorie

- Not to be confused with the calorie (lower case c), which is sometimes used in chemistry
- The heat energy to warm up one gram of water by 1°C
- 1000 calories = 1 Calorie

Nutritionists often forget to capitalize their Calorie!

Springs

- The English scientist Robert Hooke (1635-1703) noticed that for many objects, the deformation was proportional to the force causing the deformation
- Many springs obey Hooke’s Law, as long as they are not stretched or compressed too far.

Hooke’s Law

- In 1676 Hooke published his findings on the force required to stretch springs as “cedinnoopsssttuu”
- This is an anagram in Latin of the phrase Ut Pondus sic Tensia (As the weight, so the tension)
• The spring balance allows us to measure the weight of an object
• We measure the extension of the spring, that tells us how much force the object exerts on the spring

Elastic Properties of Materials
• Many solid materials behave just like springs when compressed or stretched
• Chemical bonds can also be modelled as springs
• Tendons behave as springs

Hooke’s Law for springs applies to these systems too.

Elastic Potential Energy
• Energy stored up when a spring is either compressed or stretched.
• If the spring is released, it will lose this stored potential energy, and convert it into kinetic energy (the spring moves back to the original length)
• Most materials, and even chemical bonds act like springs unless stretched too much.

Objects Move to Minimize Potential Energy
• If an object is free to move, it will move to minimize the potential energy
• The closer you are to the centre of the Earth, the lower your gravitational potential energy

Processes as Energy Interchange
• If we consider Forces
  - Drag Force
  - Gravitational Force
• If we consider Energy
  - Losing Gravitational Potential Energy (Getting nearer the ground)
  - Gaining Kinetic Energy (Speeding up as we get lower)
  - Losing Energy pushing air out of the way

• At the terminal velocity, the energy gain from KE is exactly counterbalanced by the energy lost pushing the air out of the way

• Coal, gas or oil generation of power
  - Usually generates steam which then turns turbines to generate electricity

• Hydroelectric power generation
  - Flow of water turns the turbine, which generates electricity

• Work
  - In Physics has a very specific definition:
    - An energy transfer caused by a force displacing an object

  • If a force displaces an object, then it does work on the object
  • If it does positive work, then it increases the energy of the object
  • If it does negative work then it decreases the energy of the object
For force and displacement in the same direction

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

If the force and displacement are in opposite directions, then the work done is negative

This happens when we have a braking force, trying to prevent motion

- Force of Gravity does positive work when the apple drops
- Apple gets more kinetic energy, and speeds up.

Work is a transfer of energy, and so must be measured in Joules

Power

- Power is the rate of change of energy

\[ \text{Power} = \frac{\text{Energy}}{\text{time}} \]

- This is important, because most devices have a maximum power, and so this determines how fast energy can be transferred to complete a task

Units of Power

- In the SI system, the unit of power is the Watt (W) or Joules per second (J/s)
- 1 Watt = 1 Joule/second

James Watt, 1736–1819, Scottish Engineer – developing steam engines to haul coal out of deep mines

Horse-Power

- Watt calculated the power of a horse, because he wanted to sell his steam engines to replace horses for lifting coal out of mines

- A horse can't sustain this power output for long...!
- A human can sustain 1 kW (1.2 hp) of power output briefly

The Trabant “Trabi”

The Trabant engine delivered 19 kilowatts (25 hp) from a 0.6 litre engine

It took 21 seconds to accelerate from zero to its top speed of 100 km/h
Mazda MX-5

The original version had a 1.6 L engine producing 86 kW (115 bhp)

100 km/h in 8.5 seconds and a top speed of 203 km/h (126 mph)

The Kilowatt.Hour

- The kilowatt.hour (kW.h) is a unit of energy because it is power x time
- It is often used on utility bills to calculate energy usage.

\[ 1 \text{ kW.h} = 1000 \text{ W} \times 60 \text{ min} \times 60 \text{ s} \]

\[ 1 \text{ kW.h} = 3.6 \times 10^6 \text{ J} = 3.6 \text{ MJ} \]

Average Power of the Human Body

- Average energy consumption for an adult human in one day is
  - 2500 Calories
  - Approximately 10 million Joules
- Assume this energy is converted with 50% efficiency into work by the human body in 24 hours
- Humans have a power of 60 Watts

Brain Power

- The human brain uses 20% of the energy input of the average human, so average brain power

\[ P_{\text{brain}} = 12 \text{ Watts} \]

What is Temperature?

- We use temperature in the home all the time
  - Air conditioning
  - Heating
  - Cooking
  - Air temperature outside
- But what is “temperature”??
James Joule found that by stirring water, the temperature went up. This is a transfer of energy into the water.

Temperature Scales

- The most fundamental scale is known as the Kelvin Scale (K).
- Absolute zero (0 K) is the temperature at which there is no energy of vibration, so all molecular and atomic motion stops.
- This is important in the sciences, but does not give a very useful scale for everyday use (since absolute zero is -273°C (Celsius)).

The Celsius Scale

- Sometimes called the centigrade scale (because there are 100 degrees C between the two fixed standard points).
- The freezing point of water is defined as 0°C.
- The boiling point of water is defined as 100°C.

Anders Celsius
1701-1744
Swedish Astronomer and Scientist

He originally defined 100°C as freezing point and 0°C as boiling point, but everyone ignored this...

The Fahrenheit Scale

- Fahrenheit invented the mercury in glass thermometer and defined a temperature scale with 180° between the fixed points.
- 32°F is the freezing point of water.
- 212°F is the boiling point of water.
- In his original proposal, body temperature was defined as 96°F.

Daniel Gabriel Fahrenheit (1686 – 1736) Dutch-German-Polish (born in Danzig/Gdansk, lived in the Netherlands)

Thermal Expansion

- As temperature increases, chemical bonds tend to get slightly longer.
- Increases the distance between atoms.

Face centred cubic lattice (many metals)
• Thermal expansion also works for liquids and gases, where the average distance between atoms or molecules increases.

• Hot air in the balloon expands, making the balloon float.

• Mercury in glass thermometers.
  • These work because mercury, a liquid metal at room temperature, expands as it gets hotter.
  
  General purpose thermometer, typically -10°C to +110°C

• Clinical thermometers can be shorter, because they only have to measure a limited range of temperatures.

• When building a bridge, you must allow expansion joints to be at least as large as this calculated length change over an expected temperature range.

• Heat caused by friction with the atmosphere

  White paint designed to dissipate heat

  Nose was at 150°C, with outside air temperature at -60°C

• Different amounts of expansion or contraction can be used to make materials which change shape – the bimetallic strip.

If brass and steel are bound together, then the brass expands more than the steel when heated, and the strip curves.

This type of device is widely used in thermostats and cut off devices. For example, the electric kettle.

• Run hot water over the lid. The lid expands more than the glass does.

  • The lid is then looser, so it is easier to turn.

  Jam Jar Lids and Thermal Expansion

  The supersonic airliner Concorde length expanded by 10-30 cm in supersonic flight.

  Bimetallic Strip
Heats of Transformation

- When heat is transferred into a material, instead of causing an increase in temperature, the energy may cause a change in state

<table>
<thead>
<tr>
<th>Freezing</th>
<th>Condensation</th>
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<tbody>
<tr>
<td>Solid</td>
<td>Liquid</td>
</tr>
<tr>
<td></td>
<td>Vapour</td>
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<tr>
<td>Melting</td>
<td>Vaporization</td>
</tr>
</tbody>
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- Melting – put energy into solid to break bonds
- Vaporization – put energy into liquid to pull atoms/molecules further apart
- Fusion/Crystallization – remove energy from liquid to create order
- Condensation – remove energy from vapour to create liquid

Boiling Water For a Cup of Tea

- Electrical Energy
- Thermal Energy
- Heat Up Element in Kettle
- Transfer Heat to Water
- Heat Water to Boiling Point

- Heat Up Ring/Burner on Stove in Kettle
- Transfer Heat to Water
- Heat Water to Boiling Point

Chemical Energy
- Burn Fuel
- Hot expanding gases
- Rotational Kinetic Energy
- Engine turns driveshaft
- Translational Kinetic Energy
- Gears and transmission