UNIT EM

Summary Ideas

ENERGY MODEL of INTERACTIONS

In this unit you developed your understanding of a model that explains the effects of interactions in terms of ideas about transfers of energy between objects and how they cause different types of energy associated with them to change. Below we give a historical perspective on scientists' development of similar ideas.

Historical Perspective

Up until the end of the 18th century, many of the models of different types of interactions were largely based on the idea of a special substance that flows from one object to another. For example, phenomena involving temperature changes were explained using a model in which an invisible, weightless, fluid called *caloric* flowed between objects with different temperatures. In 1798, Count Rumford rejected this idea, arguing that it could not account for the enormous amount of heat produced in friction-type contact push/pull interactions. Instead he suggested that heat was really a form of something called 'energy'.

Throughout the 19th century, Sir James Prescott Joule spent much of his time trying to understand the relationship between the energy associated with contact push/pull interactions and the changes in temperature that occur as a result of frictional effects. He developed a simple apparatus that allowed him to measure the relationship between changes in kinetic energy and changes of the temperature of water that was stirred through a contact push/pull interaction. He found that the change in energy of the moving objects during the experiment was equal to the energy necessary to change the temperature of the water from its initial to its final value. Based on work by Sadi Carnot (1842) and Rudolph Clausius (1850) the ideas emerged that; i) There are many forms of energy, and that they can be transformed from one form to another and, ii) Energy can be transferred between objects, but only while they interact with each other.

In a lecture in 1846, William Thompson (Lord Kelvin), referring to the work of Joule, announced that in his view, energy had become the primary concept on which physics was to be based. In 1847, Hermann von Helmholtz used mathematics to express that the effects of contact push/pull, light, heat, electric, and magnetic interactions were different manifestations of energy. In 1852 and 1855, W. J. Rankine declared that the term 'energy' could be applied to "ordinary motion and mechanical power, chemical action, heat, light, electricity, magnetism, and other powers, known or unknown, which are convertible or commensurable with these."

Just a few years later, Michael Faraday published an essay called, 'On the conservation of force.' He understood this to mean the transformability and indestructibility of natural powers. In the essay, Faraday discussed the ambiguities of the phrase because he understood that force can be applied and removed. Rankine argued that a better way to express what Faraday was trying to say is the phrase 'conservation of energy' which was not ambiguous, for it is *energy* that is not created or destroyed.

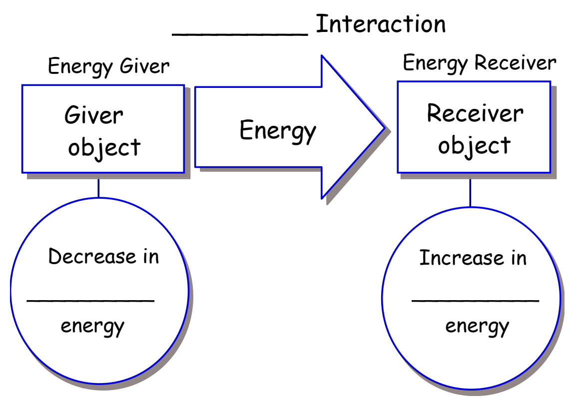
Basic Energy Model of Interactions

Idea E1 – Energy Model of Interactions.

During an interaction two objects act on or influence each other to cause some effect. During the interaction, energy is transferred between the two objects. One object is the energy giver (where the energy comes from) and the other object is the energy receiver (where the energy goes to). Because of this transfer of energy, there is a decrease in some type of energy within the giver and an increase in some type of energy within the receiver.

Idea E2 – The Energy Model of an Interaction can be described using a Giver/Receiver (G/R) energy diagram.

The energy model for a single interaction can be represented using a diagram like this.



By convention;

i) The type of interaction is identified.

ii) The names of the interacting objects are included within rectangles.

iii) The energy transferred is indicated by a broad arrow

iv) The energy changes within the objects are included in ovals attached to the objects.

In this Unit you examined several types of interactions and associated energy changes. These are summarized in the tables below and described in more detail later in this document.

<u>Interaction</u>	***<u>Conditions under which it occurs</u>***
Contact Push/Pull (CPP)	*Objects in contact push or pull on each other*
Heat Conduction (HC)	*Objects in contact have different temperatures*
Infrared Radiation (IR)	*Non-touching objects have different temperatures*
Convection (Con)	*Fluid (liquid or gas) flows between non-touching objects with different temperatures.*
Heat Interactions (HI)	*A collective name used when at least two of HC, IR and Con are occurring between objects at the **<u>same time</u>**.*
Electric Circuit (EC)	*An electrical energy source is connected to an electrical device in a*

	circuit.
Light	*Light moves from a source to a light receiver*
Sound	*Sound moves from a source to a sound receiver*

Energy Type	***Evidence for change***
Kinetic (KE)	*Change in speed*
Chemical Potential (CPE)	*Use of muscles, battery powering an electrical device., or burning of some type of fuel (such as gasoline).*
Thermal (TE)	*Change in temperature*
'Energy'	*Used as a generic term when changes are complex or varied, such as for light and sound receivers*

Energy Model of Contact Push/Pull (CPP) Interactions

Idea C1a - Definition of a CPP Interaction:

A *CPP Interaction* occurs when any two **touching** objects push or pull each other. In the absence of an equally strong opposing CPP interaction there is a change in the speed (and/or direction) of at least one of the objects involved.

Idea C1b - Duration of CPP Interactions and changes in speed:

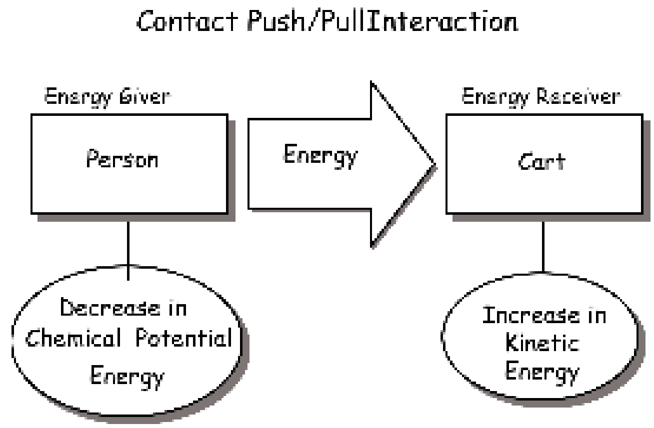
CPP interactions have a definite duration in time, and changes in speed take place gradually and continuously all the time the interaction continues.

Idea C1c – Energy transfer and changes during a CPP Interaction:

In terms of energy, during a CPP interaction there is a transfer of energy between the interacting objects. The type of energy associated with an object's motion is called *kinetic energy*, thus when the speed of an object changes during a contact push/pull interaction, so does its kinetic energy.

> ***We identified two types of CPP interactions, which are described in ideas C2 and C3. These ideas assume that the particular interaction in question is acting in isolation. That is, there is no opposing CPP interaction of equal strength that would cause there to be no change in speed (and/or direction) of the objects involved.***

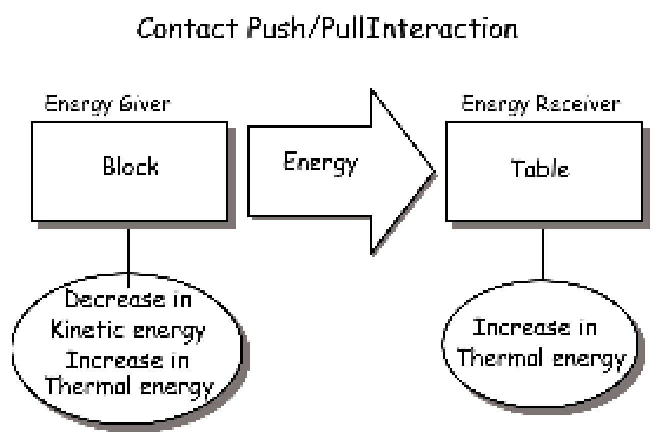
Idea C2 - CPP Interactions involving rigid objects:



One type of CPP interaction occurs when two touching **non-elastic** (i.e. rigid or stiff) objects push or pull on each other. In such CPP interactions, the speed (and/or direction) of at least one of the non-elastic objects changes while they are touching and push or pull on each other. As an example here is a G/R energy diagram describing the CPP interaction between a person's hand and a cart, that causes the cart to speed up. (Assuming the effects of friction can be ignored.)

In terms of energy, there is a change in the kinetic energy of at least one of the objects involved. If a human person is the source of the CPP interaction, then as energy is transferred out from the person, the *chemical potential energy* in the person decreases.

Idea C3 – CPP interactions involving friction:



A CPP interaction also occurs when two surfaces **rub against each other**. The evidence of such a friction-type CPP interaction is that at least one of the objects involved decreases in speed while the temperature of **both** objects increases.

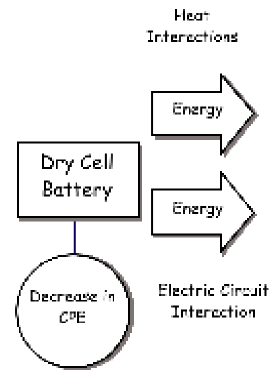
In terms of energy, during a friction-type CPP interaction there is transfer of energy between the interacting objects and a decrease in the kinetic energy of at least one of the objects involved. There is also an increase in the *thermal energy* of **both** objects. As an example here is a G/R energy diagram describing the CPP interaction in which a block slides across a table, slowing down as it does so.

Though friction can never be totally eliminated, in some situations its effects can be neglected for simplicity. This is especially true during periods when other CPP interactions (such as strong pushes and pulls) are having a strong enough effect on an object and so including the effects of friction would make little or no difference.

Energy Model of Electric Circuit Interactions

Idea EC1 – Definition of a Electric Circuit Interaction.

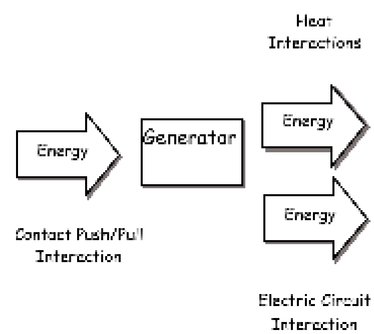
An electric circuit interaction occurs whenever a source of electrical energy (battery, solar cell, generator) is connected to an electrical device (bulb, buzzer, motor/fan, heater, etc…) in a complete circuit.



Idea EC2 – Energy Model of Electric Circuit Interactions.

During an electric circuit interaction energy is transferred from the electrical energy source to an electrical device. All electrical devices (sources and receivers) warm up when they first start to operate, meaning they increase in thermal energy.

Different types of electrical energy source operate in different ways. A dry cell battery has no energy input, but is able to transfer energy to a device because there is a decrease in the chemical potential energy stored in the battery itself. Other devices, such as a solar cell or a generator, are able to transfer energy to a device because energy is transferred into them via another interaction.



Energy Model of Heat Interactions

Idea H1 – Definition of a Heat Interaction.

A heat interaction occurs between objects that have different temperatures. During such interactions energy is transferred from the warmer object to the cooler object. When such interactions occur in isolation, the warmer object decreases in thermal energy (hence, it decreases in temperature) and the cooler object increases in thermal energy (hence, it increases in temperature). The interaction stops when the two objects reach the same temperature. (However, if energy is being transferred into the warm object at the same time, via another interaction, it is possible that it will not decrease in thermal energy.)

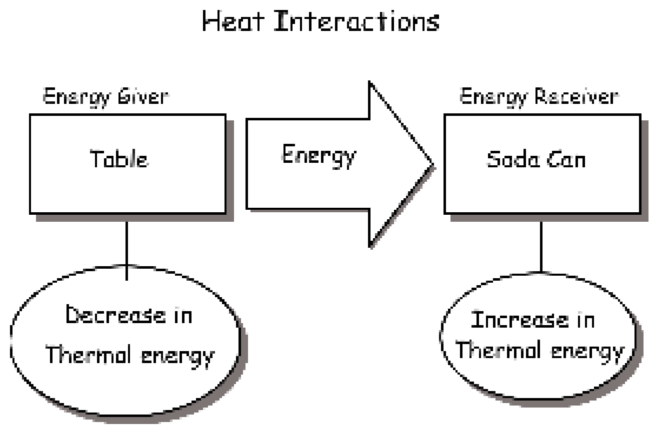
Scientists identify three specific types of heat interactions.

Idea H1a - A *heat conduction interaction* occurs when energy is transferred between any two objects that are *touching* and have different temperatures.

Idea H1b - An *infrared interaction* occurs when energy is transferred between any two objects that are *near one another* and have different temperatures.

Idea H1c - A *convection interaction* occurs when heat energy is transferred between any two objects that have different temperatures and a fluid (gas or liquid) is able to flow between them.

Idea H2 – Multiple Heat Interactions.



Under most circumstances more than one type of heat interaction can occur between two objects with different temperatures. (For example, when a cold can of soda sits on a warmer table there is a heat conduction interaction at the points where they actually touch, an infrared interaction between the non-touching parts, and a convection interaction because air can flow between them.) In such cases we simply group all the types of interaction together and call them 'Heat Interactions'. Here is a G/R energy diagram for the cold soda can sitting on the warmer table.

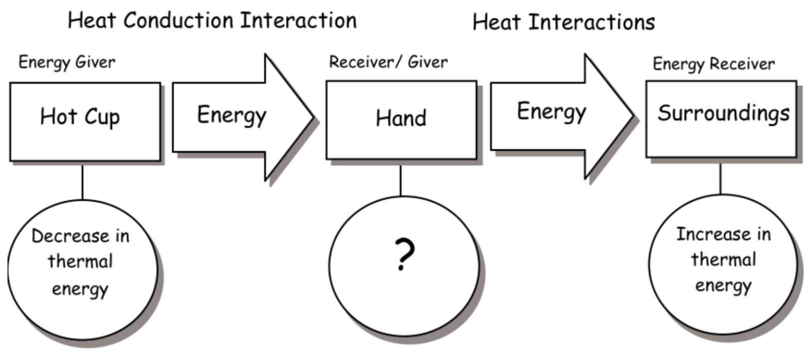
Idea H3 – Interactions with the surroundings

All electrical energy sources and devices warm up when they being to operate. Also, during any real-world CPP interaction between objects, the temperature of the objects will increase at least slightly due to the effects of friction. Because of this, some energy is always transferred from these warm objects to the surroundings (that is, all nearby and touching objects) via all three types of heat interactions. It is these interactions that are responsible for warm objects eventually cooling down.

Depending on the particular situation the amount of energy transferred to the surroundings via heat interactions may be small (even negligible) or it may be large, but in principle it always happens. The greater the temperature difference between the object and its surroundings, the greater the rate at which heat energy is transferred from a warm object to its surroundings.

Idea H4 – Transient and Equilibrium States

Any object can be both an energy receiver and an energy giver in different interactions at the same time. For example, consider a hand holding a hot cup of coffee. It is the energy receiver in a heat conduction interaction with the cup, but also an energy giver in heat interactions with the surroundings.



What happens to the thermal energy of the hand in this case depends on the relative rates of energy transfer into and out of it. If the rate of energy input from the hot cup is higher than the rate of energy output to the surroundings then the thermal energy of the hand will increase. If the rate of energy input is less than the rate of energy output, then its thermal energy will decrease. In both of these cases the temperature of the hand changes and it is said to be in a ***transient state*** with respect to its thermal energy.

However, if the rate of energy input and energy output are exactly equal, then the thermal energy of the hand will not change. This means it will stay at a constant temperature and it is then said to be in a state of ***dynamic equilibrium*** with respect to its thermal energy (usually just 'equilibrium' for short).

All electrical devices (sources and receivers) warm up when they start to operate but quickly reach a constant temperature that is warmer than the surroundings. (This constant temerpature is sometimes called their operating temperature.) While they are warming up they are in a transient state, but once the their temperature stabilizes they then remain in an equilibrium state until the circuit is disconnected. This idea can also apply to devices with moving parts, such as a generator or motor fan. While they are speeding up after first being connected they are in a transient state with respect to their kinetic energy, but they very soon reach a constant speed, which is an equilibrium state with respect to kinetic energy.

Note that it is possible for a device to be in an equilibrium state with repect to one form of energy, but not another. When we refer to a dry cell battery being in equilibrium we mean this in regard only to its thermal energy. All the time it is operating it is still decreasing in chemical potential energy.

Ideas Involving Energy Conservation

Idea C1 - Efficiency

All electrical devices (and other manufactured items) are designed with a definite purpose in mind. The energy output associated with that purpose is ***useful*** energy. Any other energy outputs are not useful. (For example, the useful energy output from a light bulb is the energy is associated with light interactions. However, a bulb also has an energy output associated with heat interactions that is not useful.)

The energy efficiency of a device is defined as the fraction (converted to a percentage) of the total energy input that is output as useful energy:

$$Efficiency\ (in\ \%) = \frac{Amount\ of\ Energy\ Ouput\ via\ Useful\ Interaction}{Amount\ of\ Energy\ Input} \times 100$$

For example, if a light bulb has an input of 50 J energy but only 4 J are output via light interactions then the efficiency is:

$$Eff = \frac{4}{50} ´\ 100 = 8\%$$

A few energy source devices, such as a dry cell battery, have no energy input while they operate but instead produce an energy output from a decrease in some form of stored (potential) energy within them. In such cases we define the efficiency of the device in a slightly different way:

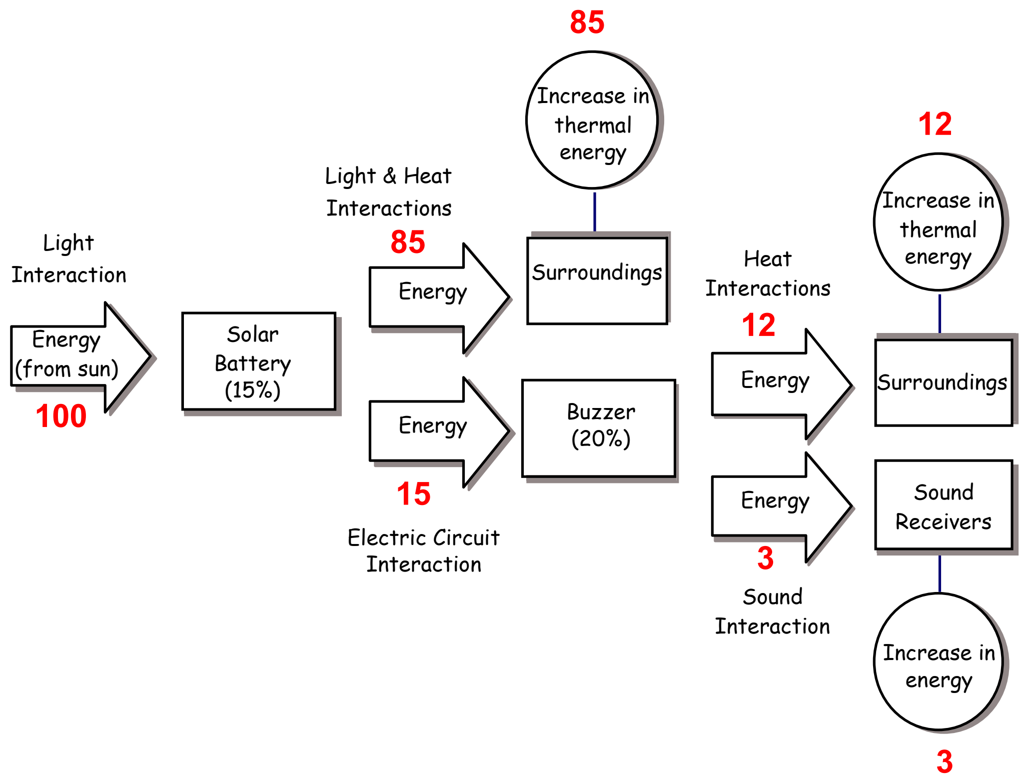
$$Efficiency\ (in\ \%) = \frac{Amount\ of\ Energy\ Ouput\ via\ Useful\ Interaction}{Amount\ of\ decrease\ in\ stored\ (potential)\ energy} \times 100$$

For example, if the chemical potential energy of a battery decreases by 60 J but only 54 J are output via an electric circuit interaction then the efficiency is:

$$Eff = \frac{54}{60} ´\ 100 = 90\%$$

Idea C2 – Keeping Track of Energy through a System:

A 'system' is any set of objects that we want to study. It can consist of a single object or a group of interacting objects and it may, or may not, include the surroundings. We can draw a G/R energy diagram showing all the energy inputs, outputs, transfers, and changes associated with the objects in the system. Using the idea of efficiency we may also be able to track amounts of energy through the system. Here is an example of such a diagram for a system consisting of a solar battery, a buzzer, some sound receivers, and the surroundings.



The input to this system is 100 J of energy from the sun via a light interaction. The useful energy output from a solar battery is that which powers an electric circuit and since its efficiency is 15% this means only 15 J are associated with the energy transfer to the buzzer. (The other 85 J is transferred to the surroundings via heat interactions, and since the surroundings have no output, this is the amount by which their thermal energy increases.)

Now considering the buzzer, it has an energy input of 15 J (from the solar battery) but its efficiency of 20% means that only 3 J of its output are associated with making sound. This 3 J is transferred to some sound receivers and, since they have no energy output, their energy increases by this amount. (The other 12 J is transferred to the surroundings via heat interactions, and since the surroundings have no output, this is the amount by which their thermal energy increases.)

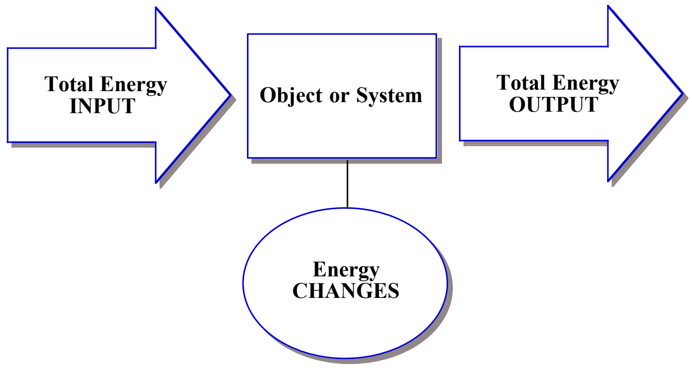
When considered together, the solar battery + buzzer system has an energy input of 100 J, but a useful energy output of only 3 J. Thus the efficiency of this system is:

$$Eff = \frac{3}{100} \times 100 = 3\%$$

Idea C3 - Law of Conservation of Energy:

Energy cannot be created or destroyed, but only changed from one form to another and transferred between objects. If, over a period of time, you keep track of the total amount of energy transferred into a system, the total amount of energy transferred out of a system, and the total energy changes within the system, then:

Energy Transferred In to System	=	Energy Transferred Out from System	+	Energy Changes within System



As an example, consider the system discussed on the previous page (a solar battery, a buzzer, some sound receivers, and the surroundings). The various relevant quantities for this system are:

Energy transferred In to System = 100 J (via light interaction with the sun)

Energy transferred Out from System = 0 J (all the energy ends up either in the suroundings or the sound receivers, which are both part of the system)

Energy Changes within System = 85 J + 12 J + 3 J (increases in thermal energy in surroudings + increase of energy in sound receivers)

So the Energy Changes + Energy output = 85 J + 12 J + 3 J = 100 J

This matches the energy input, so this means energy is conserved. (Phew!)