

**EVALUATING
ACADEMIC READINESS
FOR APPRENTICESHIP TRAINING**
Revised for
ACCESS TO APPRENTICESHIP

**SCIENCE SKILLS
ENERGY**

**AN ACADEMIC SKILLS MANUAL
for
The Construction Trades: Mechanical Systems**

This trade group includes the following trades:
Electrician (Construction, Maintenance & Industrial),
Network Cabling Specialist, Plumber,
Refrigeration & Air Conditioning Mechanic,
Sprinkler & Fire Protection, and Steamfitter

*Workplace Support Services Branch
Ontario Ministry of Training, Colleges and Universities*

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In preparing these Academic Skills Manuals we have used passages, diagrams and questions similar to those an apprentice might find in a text, guide or trade manual.

This trade related material is not intended to instruct you in your trade. It is used only to demonstrate how understanding an academic skill will help you find and use the information you need.

SCIENCE SKILLS:

ENERGY

*An academic skill required for the study of the
Construction Trades: Mechanical Systems*

INTRODUCTION

Everything that happens on a job site depends on a transfer of energy. When you pull a wire tight, you transfer energy from your arm to the wire, causing it to move. When you drill a hole in a sheet of metal, you use electrical energy instead of muscular energy to do the work. The electrical energy might be generated at a hydro-electric dam. The energy contained in water flowing over a dam is harnessed to create electrical energy. When a compressor pump sends cooling fluid through the unit, electrical energy is transformed into mechanical energy. In each example, the application of energy results in some kind of movement.

Energy is the basis of all motion - of everything that happens or changes. A description of energy requires the use of several basic scientific terms, including *force, motion, work and power*. You probably have a general sense of what each of these terms means. For example, you follow regulations to ensure that the wire you are using can withstand the different forces exerted on it. When a hoist lifts bundles of cable to an upper story, you are aware of the power of the hoist and the motion of its load. You have a good concept of what work is after a long day on the job and you also appreciate that your power tools do a lot of the work for you.

As a mechanical construction worker, you may work with machines such as electric motors and generators. Machines convert one kind of movement into another kind using levers, gears, wheels, cranks and other parts. All machines need some kind of energy to drive them. Simple machines, such as a lever used to pry out a nail, get their energy from human muscle power. Complex machines, like generators, pumps and load lifting equipment, get their energy from the potential energy stored in an electrical circuit. Machines convert this potential energy to useful work, such as heating a house or running a conveyer belt.

All aspects of the mechanical construction trades involve using energy to accomplish whatever needs to be done. You constantly use mechanical or electrical energy to complete a job efficiently and safely. Understanding the definitions of force, energy and work provides a picture of how all the forces that apply in your job situation are interrelated. This skill sheet looks at the scientific meaning of these terms. The following concepts are covered:

- ◆ Motion, energy and force
- ◆ Work and power
- ◆ Energy and its transformation
- ◆ Transfer of energy at the mechanical level
- ◆ Conservation of energy

MOTION, ENERGY AND FORCE

Just about everything that happens to an object is described scientifically in terms of its motion. **Motion** is described as a continuing change of place or position.

Motion occurs when a force is applied to an object that is free to move.

- When an engine drives the wheels of a pick-up, the truck, its load and the driver are moved along the highway. This change in position results from the force applied by the engine.

A **force** is something which changes the **motion** or position of an object. A force is felt by the object as a push or pull. An applied force results in the transfer of energy.

- When a motor drives a pump that is part of a contained cooling system, the pump exerts a force on the fluid in the tube, causing the fluid to cycle through the tube. The change in the fluid's position results from a force having been applied.
- When a dam is opened, the water moves downwards, or changes its position because the force of gravity pulls it. The energy of the moving water exerts a force on the blades of a turbine, causing them to move. As the water moves through the turbine, some of the motion of the water is transferred to the blades of the turbine.

The units commonly used to measure force are the **newton** (n or nt) in the metric system and the **pound** (lb) in the imperial system. These units are the same as the units of weight. **Weight** is the measure of one specific force, that of the earth's gravity, on the **mass** of an object.

The **mass** of an object is the amount of matter it has. Because objects have mass, they resist being moved. This resistance to being moved is called **inertia**. It is because objects have inertia that a force must be applied to get them moving and to keep them moving.

WORK AND POWER

Work is closely related to force. When a force is applied to an object, the object feels a push or pull. Usually an applied force results in the object moving, which means that the object has increased **kinetic energy**, or energy of motion.

In some cases, the force is too weak to overcome the object's inertia and so it doesn't move. The applied force is stored as **potential energy**.

- The water contained behind a dam has potential energy. When potential energy is released, it is converted to kinetic energy.

A force applied to an object can result in the object gaining kinetic energy or potential energy.

Work is the measure of any force that actually results in movement. **Work** is defined as a force exerted over a distance. The formula for work is:

$$\text{work} = \text{force} \times \text{distance}$$

or

$$W = Fs \quad \text{s is distance}$$

Whenever something moves because of an applied force, work has been done.

- Work is done when water flows over a dam to a lower level.
- Work is also done when an electric motor turns the blade of a power saw or when gasoline is burned to turn the wheels of a vehicle.

Since force can be measured and the distance an object moves can be measured, we can calculate the amount of work done. In the metric system, the unit of work is the **joule (J)**. In the imperial system, the unit of work is the **foot-pound (ft-lb)**.

Torque is a twisting or rotating force. It is the turning force that keeps the crankshaft rotating. It is a measure of an engine's ability to do work.

- Torque is the force that pushes on the crankshaft and causes it to turn. It results from the force of the piston being transferred to the connecting rod. The rod acts as a lever, transferring the up and down motion of the piston to the turning motion of the crankshaft.

Torque is calculated by multiplying the amount of force applied by the distance it is applied over. This distance is the length of the lever or connecting rod. The units of torque are pound-feet or joules.

Power is the rate of doing work. Power depends on the amount of work (W) done, divided by the time (t) required.

Example: Two electric motors need to move two 50 lb loads on two different conveyor belts a distance of 100 feet. The first of the two motors is very small, and will take several minutes to move the load. The other belt, however, is run by a larger motor, and will therefore be able to move the load in only a few seconds. Both motors do the same amount of work; however, because the second motor did the work in less time it has more power.

The formula for power is:

$$\text{Power} = \frac{\text{Work}}{\text{time}}$$

or

$$P = \frac{W}{T}$$

The metric unit of power is the **watt** (w). Because a watt is a small unit, the term kilowatt (kw), meaning 1000 watts, is often used. The unit of power in the imperial system is **horsepower** (hp).

- In an internal combustion engine, work is produced by the expanding gases in the cylinder. The faster this happens, the faster the engine speed and the greater the horsepower.

ENERGY AND ITS TRANSFORMATIONS

Why have we defined force and work before defining energy? Just as work is defined in terms of applied force, energy is defined in terms of work done.

Energy is defined as the ability to do **work** or to exert a force over a distance. Energy enables work to be done. (Since torque is a measure of a motor's ability to do work, by this definition it can also be considered the energy of the motor.) Energy might cause work (or change in motion) to be done right away or energy might be stored and released to do work later.

Mechanical energy results from forces acting on objects at the visible level. It is the kind of energy we can see and are familiar with in the everyday world. There are two kinds of mechanical energy:

- ◆ **kinetic energy** is moving energy due to an object's motion, and
- ◆ **potential energy** is stored energy due to an object's position.

Energy at the atomic level

The concept of kinetic and potential energy can also apply where we cannot see it – at the atomic level. The motion of visible objects is the result of the application of a force. In the same way, motion at the molecular level is also the result of the application of a force. This force is generated by the negative and positive charges on electrons and protons.

- ◆ Atoms can store energy as potential energy, particularly as electrical potential energy. The potential energy due to the position of electrons in a grid can later be released to do electrical work.
- ◆ Chemical reactions also release energy. Gasoline has the potential to combine chemically with oxygen, resulting in combustion. During combustion the potential energy stored in the molecules of gasoline are released as kinetic energy which drives the wheels of a vehicle.

Forms of energy at the atomic level include light, heat, sound, magnetic, nuclear, electrical and chemical energy. Energy is constantly being transformed from one form to another. Heat energy at the molecular level can be changed to visible mechanical energy. Chemical energy and nuclear energy can create electrical energy.

Energy as wave motion

Moving electrons don't just transfer energy as electrical currents. When vibrating electrons accelerate or move faster, they send out waves of energy. The amount of energy of the radiation depends on the temperature of the electrons. The hotter they are, the more energy in the wave.

Electromagnetic Radiation: the radiation sent out by electrons creates electromagnetic waves. All electromagnetic waves move through space very quickly, at the speed of light. The energy sent out by one vibration causes one wave cycle. The distance a wave moves during one complete cycle is called the **wavelength** of the wave. The number of wavelengths produced each second is called the **frequency** and is measured in hertz (Hz).

The wavelengths of energy in the electromagnetic spectrum vary from very long in radio waves and microwaves, to medium length in infrared (heat) and light waves, to very short wavelengths in ultraviolet, x-rays and gamma rays. We are most aware of light waves, which allow us to see, and infrared waves, which we feel as heat. See Figure 1.

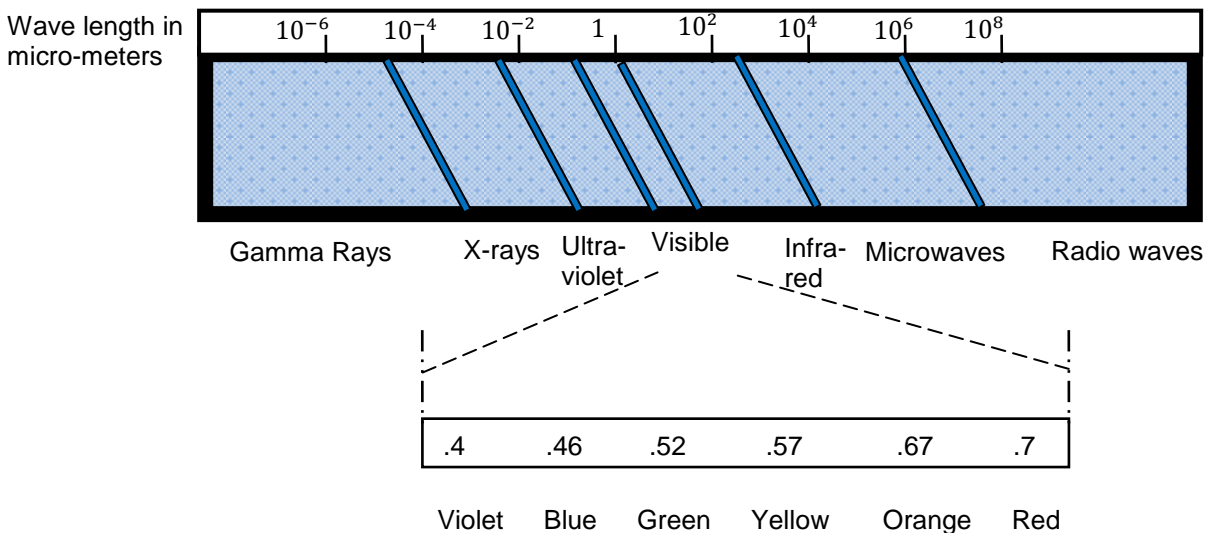


FIGURE1: The Electromagnetic Spectrum Showing Details of Visible Light

TRANSFER OF ENERGY AT THE MECHANICAL LEVEL

There is a close connection between potential energy and kinetic energy.

- ◆ Anything that moves has kinetic energy. The total kinetic energy of a moving object is the same as the amount of work done by the object.
- ◆ Potential or stored energy is acquired when an object is moved or held against a force, such as water behind a dam.
 - Work must first be done to an object place to give it potential energy.
 - When air is compressed in a pneumatic tool, work done to compress the air can be released as kinetic energy when the air flows out to operate the tool.

- When an object with potential energy starts to move, it starts to do work.
 - Its potential energy begins to change to kinetic energy.

Potential energy is the “not yet used” ability to do work. It is like having a force deposited in your account in the bank. At some future time, you can take it out and spend it. Kinetic energy is the spending spree. The force in the bank has been withdrawn and is being used to cause motion.

The unit of potential and kinetic energy is the *joule*, which you will recall is the same as the unit for work.

Example: A thrown ball rises in the air with a certain amount of kinetic energy. The kinetic energy gradually gets changed to potential energy as the ball moves against the pull of gravity. At the point where the force of gravity finally stops the upward motion of the ball (the highest point), all the kinetic energy is now converted to potential energy. The ball has no motion but it has lots of potential to fall back down.

As gravity pulls the ball back to earth, the potential energy is gradually changed back to kinetic energy. Once the ball hits the ground and stops, gravity can no longer cause it to move. All of the kinetic and potential energy has been transferred to the ground. See Figure 2.

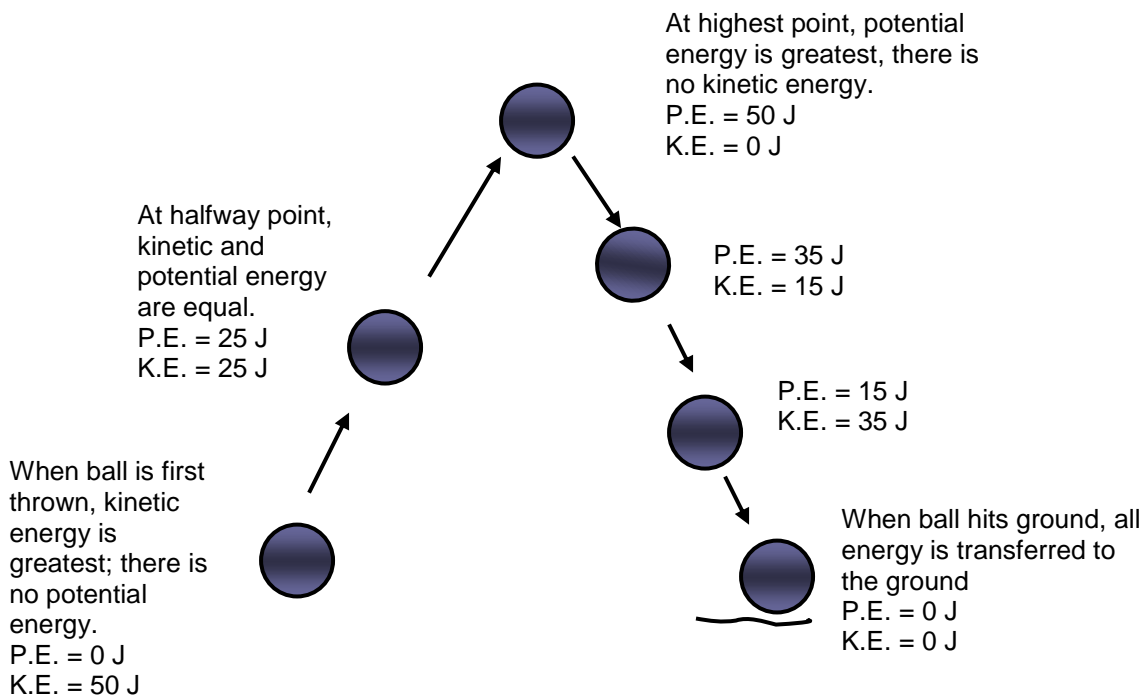


FIGURE 2: Kinetic and Potential Energy are Closely Related

When the ball is in the air, the amount of kinetic energy it has keeps changing, as does the amount of potential energy. As kinetic energy increases, potential energy decreases; as kinetic energy decreases, potential energy increases. However, the sum of the two energies is

always equal to the original amount of energy transferred to the ball when it was thrown. Once the ball hits the ground, all the energy is transferred to the ground.

Let's look at what happens to the relative amounts of potential and kinetic energy when a ball is thrown upwards with 50 joules of energy.

- You can see from Figure 2 that the amount of kinetic energy is greatest when a ball is first thrown upwards and also just before it returns to the ground.
- As the ball moves upward against the force of gravity, its potential energy increases at the same rate as the kinetic energy decreases.
- At the highest point in its trajectory (path), it actually stops moving for an instant. At this point, it has its greatest amount of potential energy and no kinetic energy at all.
- As soon as it starts to fall downwards, its potential energy decreases at the same rate as the kinetic energy once again increases.

Your arm muscles did 50 joules of work in throwing the ball. At different times in its flight, the specific amounts of kinetic energy and potential energy vary but the total amount of energy always equals 50 J, until the ball hits the ground.

CONSERVATION OF ENERGY

Energy is never used up or destroyed, it just changes form and gets transferred around.

Chemical energy can be transferred to heat energy, as when natural gas is burned in a furnace to create heat that warms a building. When one type of energy changes to a different form, no energy is lost in the process. There is the same amount of total energy after the change as before.

This concept is expressed as the **Law of Conservation of Energy**: *Energy cannot be created or destroyed, but it can be converted from one form to another.*

We saw this in Figure 2. When a ball is thrown with 50 J of kinetic energy, at every point in the trajectory there is a total of 50 J of energy acting on the ball. This is so until the 50 J of energy is transferred to the ground. If the ball was a wrecking ball, the 50 J of energy would be transferred to the walls of the building that was being demolished.

We control the conversion of potential energy to kinetic energy in order to do useful work. However, not all the energy released is available to do useful, mechanical work. Some is changed to other forms of energy.

- When we run a motor using the energy from electricity, not all of the energy released is converted to mechanical work or torque.
 - Some of the energy is lost as heat and sound.
- When we turn on a light, some of the electrical energy in the light bulb is converted to heat.
 - Some of the heat energy in a heating element is converted to light.

Throughout all these energy transformations, the total amount of energy remains the same.

EFFICIENCY OF MACHINES

When a machine is used to transform energy, such as when electrical energy is changed to mechanical energy in an electrical power saw, the same amount of energy that goes into the system comes out but not all the energy is available to do work for us.

- The amount of electrical energy going into the tool is not the same as the amount of energy the machine actually has available to transform into mechanical force used to cut wood.
- Overcoming the friction that occurs between parts of the machine uses some energy which is not available for work.

The difference between the energy that goes into a machine and the energy actually transformed into work tells us about the *efficiency of the machine*”.

Have you noticed how a power tool gets hot if you use it for a while? The heat is produced from the input energy but is not used to power the machine; this heat energy flows into the atmosphere and is not available to do the work you want the machine to do.

The efficiency of an electrical tool can be calculated.

1. First the energy going into the machine is measured.
2. Then the actual energy output of the tool is calculated.
3. The measurement of the output is placed over the measurement of the input to make a ratio.
4. The ratio is multiplied by 100 to make the ratio into a percent.:

Example: If the input of a power saw is 50 joules and the output, in work, is 40 joules, what is the efficiency of the energy transformation?

$$\frac{40}{50} \times 100 = 80\%$$

If you are told a saw is 85% efficient, you know that 15% of the input energy is not used by the tool to produce work but goes elsewhere.

Our ability to design and use machines continues to change dramatically the way we live. We can harness energy and direct it into machines that will do all kinds of work for us. In the last one hundred years, we have learned how to produce and control electrical energy to run machines that have liberated us from doing physical work.

Now another machine dependant on electricity, the computer, is liberating us from doing mental work. We have come a long way from our start with the lever and inclined plane but the concepts of energy and force that underlie all these vastly different machines remains the same.

CONCLUSION

To sum up, let's look at the production of electrical energy in a battery to illustrate several energy transformations. When chemical changes take place in the electrolyte solution in the battery, the energy released causes negative charges to increase on one plate and positive charges to increase on the other plate.

The electrons have the potential to move through the wires and do electrical work such as running the lights. But this energy is stored until the circuit is connected or the lights are turned on.

The potential energy changes to kinetic energy when the electrons are free to move in the wires. The kinetic energy is used to create light and heat in the light bulbs of the circuit.

The generation of electricity at a hydro-electric dam also illustrates the way potential energy is converted to motion. When water is contained behind a dam, the force of gravity exerts pressure on the water. This force creates potential or stored energy in the water.

If the dam is opened, the potential energy of the water changes to kinetic or moving energy as the water moves through the turbines. The kinetic energy of the water is used to generate electrical energy. The electrical energy is stored in wires as potential energy. This potential is used to do work, or create motion, when an electrical appliance is started.

Throughout all these energy changes, no new energy is created or destroyed. The available energy is only transformed from one form to another.

Answer the following questions about potential and kinetic energy by putting the correct word in the blank. Answers are on the last page.

1. Kinetic energy is the energy due to the _____ of an object.
2. Anything that changes or tries to change the motion of an object is called a _____ .
3. Energy that is stored to do work at a later time is called _____ energy.
4. The units of force and weight (the force of gravity) are the same. The unit of both force and weight in the metric system is the _____ .
5. Energy is defined as the ability to do _____.
6. Work is force exerted over a distance. The metric unit of both work and energy is the _____ .
7. When a ball is first thrown upwards, its _____ energy is at a maximum and its _____ energy is at a minimum.
8. When the chemical energy in fuel is converted to torque in an engine, not all the energy is available to do useful work. Some of the energy is converted to _____ and sound because of friction.
9. Energy is never used up; it just gets _____ from one form to another.
10. Choose the best answer.
If a ball is thrown upwards with 30 joules of energy, at the points halfway up and half way down, its potential and kinetic energy are:
 - a) unbalanced.
 - b) each 15 joules.
 - c) each 0 joules.

ANSWER PAGE

1. motion
2. force
3. potential
4. newton
5. work
6. joule
7. kinetic, potential
8. heat
9. transformed, changed or converted
10. b) each 15 joules