EVALUATING
ACADEMIC READINESS
FOR APPRENTICESHIP TRAINING
Revised for
ACCESS TO APPRENTICESHIP

SCIENCE SKILLS
PHYSICAL PROPERTIES OF MATTER

AN ACADEMIC SKILLS MANUAL
for
The Precision Machining And Tooling Trades

This trade group includes the following trades:
General Machinist, Tool & Die Maker,
Mould Maker, Pattern Maker, and
Machine-Tool Builder Integrator

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
PHYSICAL PROPERTIES OF MATTER

An academic skill required for the study of the Precision Machining and Tooling Trades

INTRODUCTION

An object such as a sheet of metal can be described by its physical characteristics. These physical characteristics include whether it is a solid, liquid or gas. The metal is a solid object, although in forming the steel, the iron had to be heated until it melted. In this molten or liquid state, the steel was cast in a mould to harden into the required form. Other physical properties of the metal sheet can be measured and described, including its volume and weight.

The sheet exerts a downward pressure when it is placed on the floor. Thick steel cannot be easily bent, but it can be rolled so that it becomes thinner. A thin piece of steel is easy to bend but hard to break. It can be cut, sanded, painted and attached to a framework. A machinist can pick from different types of metal to find the one most suitable for the job being done. Metal sheets can vary in colour, hardness, rust resistance and texture.

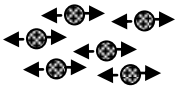
In this skills manual, we will look at some physical properties of matter including:

- Three states of matter
- Volume
- Weight and mass
- Pressure
- Density
- General properties of solids
- General properties of liquids
- General properties of gases

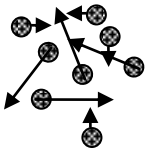
THE THREE STATES OF MATTER

Matter occurs in one of the physical three states, as a solid, liquid or a gas. The physical state of a substance at a given temperature depends on the amount of heat or kinetic energy possessed by the molecules that form it. These molecules have the ability to absorb heat. As the amount of heat increases, the kinetic energy of the molecules also increases and causes them to vibrate or move more rapidly.

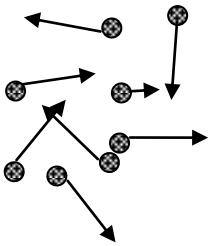
The molecules of solids, liquids and gases have differing amounts of kinetic energy and so they move in different ways. See Figure 1.



Molecules of a solid
Molecules of a solid vibrate back and forth in one spot. They have low kinetic energy



Molecules of a Liquid
Molecules of a liquid, although still close together, slide over each other more easily. They have more kinetic energy.



Molecules of a Gas
The molecules of a gas move apart rapidly in all directions with a high amount of kinetic energy,

FIGURE 1: Molecular Motion and the Three Physical States of Matter

Because heat affects the amount of kinetic energy in a substance, the physical state of a substance depends on the amount of heat present. If a solid substance gains enough heat, it moves with more kinetic energy and will change into a liquid. If a liquid absorbs enough heat, it changes into a gas.

Solids, liquids and gases have different general characteristics. Usually substances occur in one or, at most two, states at the temperatures normally found on earth. Water is an exception. It can be found as solid ice, as liquid water and as a gas called water vapour. Other substances such as metals only become molten or liquid if they are heated to a much higher temperature.

Solids
*A **solid** has a definite shape and volume*. Molecules in a solid vibrate (jiggle) but generally do not move from place to place. They are tightly packed, usually in a regular pattern. Most objects you work with are solids.

- Objects such as wire and sheets of metal maintain their shape and volume unless they are broken apart into smaller solids.
- Plastics are solids that have been poured into molds as a liquid. They harden into solids at room temperature. Some machine parts are now being made from plastic because it can be formed into whatever shape is needed, it is lighter than metal and it absorbs energy.
- ♦ Iron usually exists as a solid. It becomes liquid only if a large amount of heat is added to cause it to melt. Once molten steel cools, it becomes solid again.

Liquids
*A **liquid** has a definite size or volume but not a definite shape.* The molecules in a liquid vibrate, move about, and slide past each other. They are close together with no regular arrangement. A liquid takes the shape of the container in which it is held and presses on the container in the same amount in all directions.

- ♦ Many liquids, such as cleaning agents, are solutions with water or a mild acid used as the solvent.

Gases

*A **gas** has no definite volume or shape.* The molecules in a gas vibrate and move freely at high speeds. They are well separated with no regular arrangement.

- Air, the most common gas found in a building, is actually a mixture of different gases such as oxygen gas and carbon dioxide gas.
  - In a tightly insulated building, gas molecules such as carbon monoxide can build up to harmful levels because they can't leak out of the building. An air exchanger is installed so that inside air is replaced with outside air.

All substances have the physical properties of as volume, weight, mass, center of gravity, inertia, pressure and density. These properties are interconnected and depend on an object's size, weight and the types of molecules it is made from. They also depend on whether an object is a solid, liquid or gas. We will look at some of these properties.

VOLUME

***Volume** is the amount of space an object occupies.*

A solid* has *definite shape and volume. The bonding forces that occur between its molecules hold them in a fixed position. In other words, the space a solid occupies remains relatively constant, as does its external boundaries.

- The volume of a rectangular solid can be calculated by multiplying together the measurements of its length, width and height.
- The volume of an irregular solid is calculated by measuring the quantity of water it displaces.

A liquid has a definite volume but no definite shape. The space it occupies (its volume) stays the same no matter what kind of container it is held in but it will flow to take the shape of the container.

- The volume of a liquid is found by pouring it into a graduated measuring cup. We read the amount of volume occupied by the liquid from the measurements on the side.

A gas has no definite volume or shape. Gas molecules usually exist as independent particles. Each particle has its own molecular volume. If a gas is confined in an enclosed area, the gas molecules will expand to completely fill the area they are contained in.

- The volume of a gas held in a container depends on the size of the container.
- The volume of a gas in a flexible container is not constant but varies with the temperature and the outside pressure exerted on the container.
  - If a flexible container holding a gas has outside pressure exerted on it, the volume of the gas (and the container) will get smaller as the pressure increases.
  - If the temperature of the gas rises, the gas molecules become more active. This increases the pressure on the container and expands its walls, thereby increasing the volume of both the gas and the container.

WEIGHT AND MASS

In scientific terms, weight and mass are different properties.

*The **weight** of an object is a measure of the force of the earth's gravity pulling on its mass.* The basic unit of weight in the metric system is the ***newton (n)***, while in the imperial system it is the ***pound (lb)***. Since the pull of gravity (weight) is a universal force, the units of weight, the pound and Newton, are used as the standard unit for all types of mechanical forces.

- The weight of an object can be found using a spring or digital scale.
    - A solid can be placed directly on the scale and measured.
    - A liquid or a gas must be placed in a container of a known weight before they are measured. The weight of the container is then subtracted from the total weight to get the weight of the liquid or gas.

Mass** is a measure of the amount of matter in an object.* The basic units of mass are the ***gram and the ***kilogram***.

- Mass is measured with a balance scale against a standard mass.
- The mass of an object remains constant while its weight can vary, depending on how close the object is to the surface of the earth.
    - The closer to the earth an object is, the stronger the pull of gravity and the greater the weight.

In everyday use, we tend to refer to weight and mass as being the same thing. The term kilogram tends to be used for both mass and weight in the metric system, just as the term pound is used for both mass and weight in the imperial system.

Inertia

The amount of matter or the mass of an object gives it a resistance to being moved. This resistance is called ***inertia***. ***Inertia** is the resistance of any physical object to a change in its state of motion or rest.*

- This means that an unmoving object will not move unless a force acts on it; and
- an object in motion will not change its speed or direction unless a force acts on it.

The amount of matter or the mass of an object gives it its inertia.

- The more mass an object has, the more inertia it has.
    - A bundle of metal bars has more resistance to being moved than a carton of light bulbs because it has more mass and thus it has more inertia.
    - A train is harder to stop than a bicycle.

Center of Gravity

*The weight of an object is considered to be concentrated in a central point called the **center of gravity**.* The stability of an object depends on how wide a base it rests on and how low its center of gravity is.

- A short, wide machine is more stable than a tall, narrow one because it has its weight distributed over a wider area and its center of gravity is lower. The tall, narrow machine can be pushed over more easily.
- A slab of metal that is lying flat is more stable than one that is standing on its end because its weight distributed over a wider area and its center of gravity is lower.
- When you are up on a ladder, you can't reach over too far. Once the ladder starts to lean, its center of gravity moves away from the support of the wall and then the force of gravity causes it to fall to the ground.

PRESSURE

***Pressure** is defined as continuous physical force exerted on or against an object by something in contact with it.* We feel pressure when someone leans on us. We apply pressure when we push against a heavy machine.

Solids and pressure

Because of their weight (the pull of the earth's gravity), solids exert a pressure in a downward direction over the area they are resting on.

- The pressure exerted on machine parts must be considered when calculating how strong those parts should be.

Liquids and pressure

Like solids, liquids exert a downward force or pressure because of their weight. Liquids also exert pressure in a sideways direction because their molecules flow over each other and move in all directions.

- If a liquid is completely enclosed, such as in a pipe, it will exert pressure evenly in all directions.

Gases and pressure

Gases confined in a container also exert pressure evenly in all directions. Gas molecules are continually in motion, bouncing off any surface they collide with and then continuing in a new direction. These collisions create a pressure known as gas pressure. The pressure exerted by a gas depends on its volume and its temperature.

The pressure exerted by a gas depends on its volume and its temperature.

- Gas can be contained in a cylinder under pressure and used to power tools such as air guns, paint sprayers, sandblasters and drills. These pneumatic tools or air tools are driven by compressed air supplied by a gas compressor.
- You can see the evidence of gas pressure when you blow air into a balloon. If too many gas molecules are blown into the balloon, the pressure from the gas will eventually cause it to burst. As we said earlier,

Calculating pressure

The pressure of an object is calculated by dividing its weight by the area on which it exerts pressure. If you press on a wall with your finger, it won't make much of an impression. But if you press a tack on the wall with the same weight (or force), it will penetrate into the wall. The point of the tack presses on a much smaller surface area than the end of your finger. Although the weight of both objects is the same, the surface area of the tack is smaller. This increases the amount of pressure it exerts.

The formula for pressure is:

Pressure = force divided by area
or
P = F/a

In the metric system, the unit of pressure is newtons/m^2, called a ***pascal (Pa)***. This is a very small amount, so the unit for a thousand pascals, the ***kilopascal*** (***kPa***) is more often used.

In the imperial system, the unit of pressure is ***pounds per square inch (psi)***.

DENSITY

Density *is defined as the mass or weight per unit volume*. Density is the quality of lightness or heaviness of an object. When we pick up an object, we have a feel for whether it is light or heavy. But sometimes we need a more precise definition of heaviness and lightness. In that case, we use the term density.

- During a work day, you might struggle to lift a drill into place, but you might easily carry a large box of light bulbs. The light bulbs are easy to carry because they are light, while the drill is heavy.
- If you had two cartons the same size, one containing screws and the other containing only packing material, the carton with screws in it would be denser. Although the volumes of the two cartons are the same, the weights of the objects inside are different, resulting in different densities.
- Steel is denser than aluminum. A cubic centimeter of steel is three times as heavy as a cubic centimeter of aluminum.
- Wood is less dense than either steel or aluminum and a cubic centimeter of it would weigh less than either of them.

Calculating density

The density of a solid is found by dividing its weight or mass by its volume. The formula for density is:

D = w/V

Example: You have to hoist a load that has a mass of 150 kilograms and a volume of .5 m^3. What is its density?

D = m/V
= 150 kg/.5 m^3
= 300 kg/m^3

Specific gravity
Sometimes it is useful to compare the density of one substance to another. The density of water has been chosen as the standard to compare the densities of all solids and liquids. *The ratio of the density of a solid or liquid to the density of water is called its* ***specific gravity****.*

$$\text{Specific gravity} = \frac{\text{density of substance}}{\text{density of water}}$$

The density of water in the metric system is 1 gram per cubic centimeter. The density of the other substance must also be in the same units as water in order to make the comparison.

- Lead acid batteries produce electrical energy by chemical processes that charge and discharge the battery.
  - The electrolyte inside the battery is made of a solution of sulphuric acid and water.
  - Sulphuric acid is heavier than water, so a mixture of 64% water and 36% acid will be denser than water alone.
  - The liquid in the battery will have a specific gravity of 1.27 at 24 ^{o}C when the battery is fully charged.
  - At this point, all the electrical energy is in the form of potential energy.
- As the battery discharges, producing usable electrical energy, the sulphuric acid gets transformed in the process.
  - In the discharged state, there is about 17% sulphuric acid and 83% water.
  - The specific gravity of the battery's liquid will now be lower than that of a fully charged battery.
- You can tell how much charge is left on a battery by reading the specific gravity.
  - Most lead acid batteries have built-in hydrometers that read the specific gravity, comparing it to that of a fully charged battery, and telling you the state of charge.

GENERAL PROPERTIES OF SOLIDS

Hardness and toughness
Hardness *means resistance to penetration.* Different solids have different degrees of hardness.

- Steel is harder than wood. It is easier to saw through a piece of wood than a steel rod.

Toughness *is the ability to withstand heavy impact forces without fracturing.*

- Aluminum will bend and break more easily than steel.

***Durability** relates to the combined properties of hardness and toughness.*

- Steel is more durable than tin.

Cohesion and adhesion

***Cohesion** is the term used to describe the way a solid remains as an individual object with definite boundaries.*

Tensile strength is related to cohesion. It *is the ability to resist being pulled apart.*

- If a steel wire and a copper wire of the same diameter are pulled with the same force, the copper wire will break first. The steel wire has a greater tensile strength.

***Adhesion** is the ability of one solid to stick to another, the way glue sticks to the surface of a frame.*

- Paint will stick to a surface and it also has fairly low cohesion so it can flow into small cracks.

Ductility and malleability

***Ductility** means that metal can be pulled through two heavy rollers so its diameter decreases but its length increases.*

***Malleability** means that metals can be hammered or rolled so that shape and thickness are changed considerably.*

- Because steel has these properties, it can be formed into the shape and strength needed for a specific job.

Elasticity and stiffness

A solid also has a certain amount of ***elasticity***, *the ability of an object to resume its original shape after it has been distorted by a force.* When a solid's elastic limit is exceeded, the solid breaks or is permanently distorted. *The opposite of elastic is **brittle.***

- A thin sheet of metal piece can be bent and held in place but it can go back to being flat if it is released.
- A piece of wood has good elastic properties. A board that is bent in order to force it into place will return to its original shape once we stop bending it.
- A piece of wallboard is brittle and if it is bent, it will usually break.

***Stiffness** is a measure of how much force is required to bend a certain material.* A stiff material requires a lot of applied force before it will bend.

- Good structural materials like wood and steel are both stiff and elastic.
- Steel changes in its stiffness depending on its shape and thickness.
- A thin sheet will bend easily while a steel rod is stiff.

Alloys: Much of the material you use on the job is made from metal alloys. When one metal element dissolves another metal or nonmetallic element, a metal ***alloy*** is formed. Steel is an alloy of iron, carbon, and small amounts of other elements.

The metals that form an alloy are melted at high temperatures before they are mixed. When the mixture cools into a solid, the molecules of each metal in the alloy remain close together but each one retains some of its individual properties. Steel, for example, has much more iron than other elements, so most of its characteristics resemble iron.

However, an alloy also has physical properties that are unique to it. This means that an alloy behaves differently than the pure metals that form it.

- A steel alloy of iron and nickel will have a lower melting point than either iron or nickel alone.

GENERAL PROPERTIES OF LIQUIDS

The molecules of a liquid are close together, but they can move over each other. Substances that are liquid at room temperature have enough kinetic energy to *partially* overcome the binding forces that cause solids to remain in their fixed position. This is the reason a liquid can flow and take the shape of its container while still maintaining a definite volume. Because of this flowing motion, liquids have different properties than solids.

Surface tension: Although the bonding force is weaker in a liquid than a solid, it is still there. The bonding force between liquid molecules attracts all molecules equally in all directions, except the ones on the surface. Molecules at the surface are affected only by a downward, attractive force because there are no molecules above to provide an upward attraction.

This downward force is strong enough to give liquids one definite surface. This pull is called ***surface tension***. Surface tension prevents the liquid molecules from escaping at its top surface. So, a liquid maintains a definite volume with a level surface.

Buoyant force: Surface tension enables a liquid to support light objects such as a block of wood. This is called the ***buoyant force*** of liquids. It also causes a drop of liquid to assume a spherical shape (a raindrop). The force of gravity is always present and it tends to pull the liquid into a flatter shape.

- Mercury has a high surface tension, so a small drop of mercury is almost spherical. A larger drop becomes flatter because it is more susceptible to the pull of gravity.

Viscosity: The friction created as one liquid molecule flows over another is called ***viscosity***. Viscosity has the effect of slowing down the flow of the liquid. As the temperature rises, viscosity decreases and a product such as calking will flow more easily.

- You choose a caulking based on its adhesion and the viscosity *and* the environmental conditions it will be exposed to.

- Oils used to lubricate machine parts have varying viscosity ratings depending on their applications.

GENERAL PROPERTIES OF GASES

Gases have many characteristics in common with liquids. The main difference is that gases can be compressed while liquids do not compress very much. We say that gases are compressible.

Volume and pressure: Gases do not have a definite volume. If a flexible container holding a gas has outside pressure exerted on it, the volume of the gas (and the container) will get smaller as the pressure increases. We say that the gas is compressed.

- Compressed gas has many applications in the construction trades. Pneumatic drills and other tools rely on compressed gas
- Compressed air is used to inflate vehicle tires. When a tire is filled, the increased inside air pressure causes the tire to expand until it is inflated to the proper amount. If there is not enough air pressure, the tire is soft and mushy, while too much air pressure can cause a tire to explode.

Diffusion: Two gases of different densities placed in a container will mix together quickly because of the rapid motion of gas molecules. The kinetic energy that imparts the quick, random motion to gas molecules is greater than the pull of gravity and so the two substances diffuse together. Gases can also diffuse through porous solids.

- To protect yourself from breathing in a toxic gas, you need to wear a mask that prevents the gas from moving through it.
- To prevent warm air molecules from diffusing through the walls of a building, you need to apply insulation and a vapour barrier.

CONCLUSION

The physical properties of a substance are used to describe a substance. The physical characteristics of an object also affect how it will behave.

Substances exist in three different physical states: solid, liquid or gas. We are mostly concerned with the state of substances as they occur at the earth's temperature.

Solids, liquids and gases have different general characteristics. We are familiar with the rigid nature of solid objects. They maintain their shape and volume unless they are broken apart into smaller solids. Because solids have weight, they exert pressure in a downward direction.

Liquids flow in their container but maintain a definite surface tension. The volume of a liquid doesn't change when it is poured into another container. The flowing movement of liquid molecules exerts pressure in all directions, not just in a downward direction.

Gases are basically free-moving, independent particles that travel at high speeds in all directions. If different types of gases are released into a room, the molecules will move around randomly until they are mixed together evenly. The volume of a gas in a flexible container is not constant but varies with the temperature and the outside pressure exerted on it.

Answer the following questions. Answers are on the last page.

1. The physical state of an object at a certain temperature and pressure depends on the amount of kinetic _____ possessed by the molecules that make up the object.

2. Solids have a definite shape and _____.

3. Liquids have a definite volume but take the _____ of their container.

4. Gases have no definite _____ and no definite _____.

5. Volume is the amount of _____ an object occupies.

6. The volume of a gas in a flexible container will change as the _____ and _____ change.

7. Weight is a measure of the force of _____ on an object.

8. The more mass an object has, the more _____ it has and the more force must be applied to move the object.

9. Objects have the property of density, which is defined as weight per unit _____.

10. Pressure is the force per unit _____ .

11. The unit of pressure in the imperial system is _____ ____ _____ _____, abbreviated as psi.

12. Solids exert pressure in a _____ direction.

13. A material such as thin steel that will bend and then return to its original shape has high _____ .

14. Metal that is distorted can be hammered back into shape. This property is called _____ .

15. Liquids maintain a definite volume because of a downward attractive force on the molecules at the surface. This force is called _____ _____.

16. The viscosity of a liquid affects the rate at which it will _____ .

ANSWER PAGE

1. energy
2. volume
3. shape
4. volume, shape
5. space
6. temperature, pressure
7. gravity
8. inertia
9. volume
10. area
11. pounds per square inch
12. downward
13. elasticity
14. malleability
15. surface tension
16. flow