Modern Refrigeration and Air Conditioning

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Chapter 1

Fundamentals of Refrigeration

Modules

- History and Fundamentals of Refrigeration
- Temperature, Pressure, and Measurement
- Refrigeration Systems and Terms

Learning Objectives

- Describe the early development of refrigeration.
- Discuss the basic physical, chemical, and engineering principles which apply to refrigeration.
- Explain how cold preserves food.
- Define basic refrigeration terms.
- Explain principles of heat transfer.
- Compare Fahrenheit, Celsius, Kelvin, and Rankine temperature scales.

Learning Objectives

- Use temperature conversion formulas to convert from one temperature scale to another.
- Determine area and volume of cabinets.
- Explain the difference between psia (absolute pressure) and psig (gauge pressure).
- Describe the basic operation of a refrigerator.

Learning Objectives

- Discuss the differences between sensible heat, specific heat, and latent heat. Describe their applications.
- Explain physical laws that apply to refrigeration.
- Demonstrate and explain the relationship between SI metric and U.S. conventional measurement.
- Recognize and use various symbols for SI metric units of measure.

Learning Objectives

- **Make conversions between the U.S. conventional and SI metric systems of measurement.**
- **Calculate the enthalpy of water at a variety of temperatures.**
- **Follow approved safety procedures**

Chapter 1

HISTORY AND FUNDAMENTALS OF REFRIGERATION MODULE

1.6

Fundamentals

- **Temperature**
  - **Measures the speed of motion of the atom.**
- **Heat**
  - **The thermal energy of the atom multiplied by the number of atoms (mass) affected.**

1.6.1

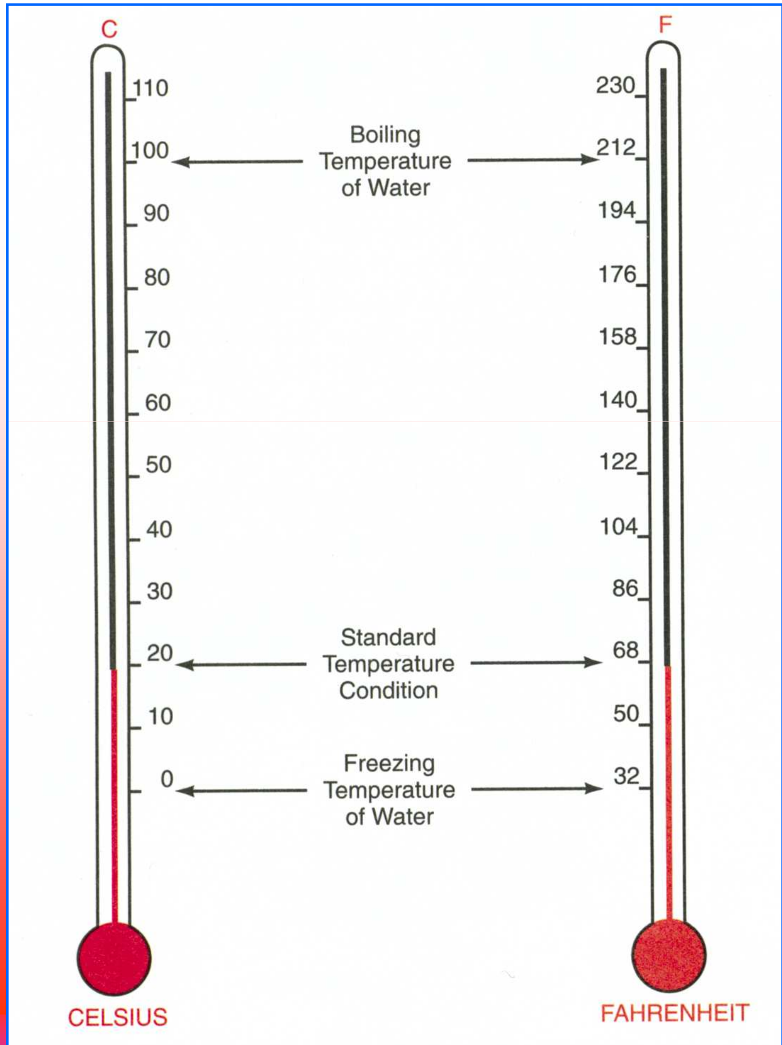
Fundamentals

continued

- Two Units of Temperature Measurement
  - Fahrenheit
    - The U.S. conventional unit of temperature — ice melts at 32°F, water boils at 212°F.
  - Celsius
    - The SI unit of temperature — ice melts at 0°C, water boils at 100°C.

1.6.1

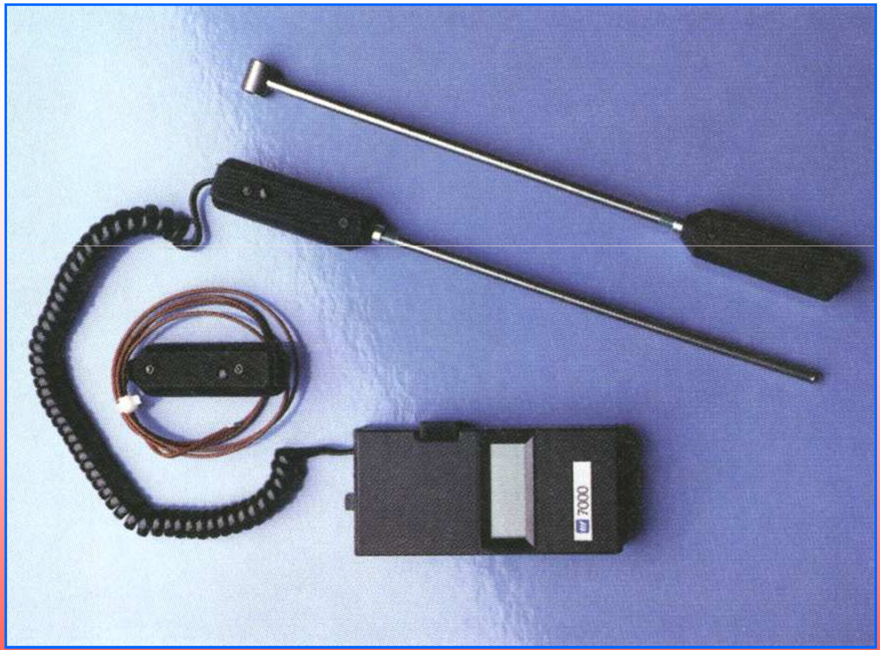
Fundamentals



A comparison of Celsius and Fahrenheit thermometer scales.

Fundamentals

continued



Thermometer-pyrometer

- **Measures from –40°F (–40°C) to 1999°F (1100°C)**

1.8.1

Temperature Conversions

Degrees Celsius to Degrees Fahrenheit Formula:

$$\text{Temperature in °F} = \frac{180}{100} \times \text{Temperature °C} + 32$$

Temperature Conversions

1.8.2

Degrees Fahrenheit to Degrees Celsius Formula:

$$\text{Temperature in } ^{o}C = \frac{100}{180} \times (\text{Temperature } ^{o}F - 32)$$

or

$$\text{Temperature in } ^{o}C = \frac{5}{9} \times (^{o}F - 32)$$

1.10.1

Linear Measurement

U.S. Conventional Units of Measurement

Measurement	How to Express the Measurement
0.001 in.	one-thousandth of an inch
0.01 in.	one-hundredth of an inch
0.1 in.	one-tenth of an inch
1/64 in.	one sixty-fourth of an inch
1/32 in.	one thirty-second of an inch
1/16 in.	one-sixteenth of an inch
1/8 in.	one-eighth of an inch
1/4 in.	one-fourth of an inch
1/2 in.	one-half of an inch

1.10.1

Linear Measurement

Units of Conventional Linear Measurement

12 inches = 1 foot
3 feet = 1 yard
5280 feet = 1 statute mile
6080 feet = 1 nautical mile

1.10.1

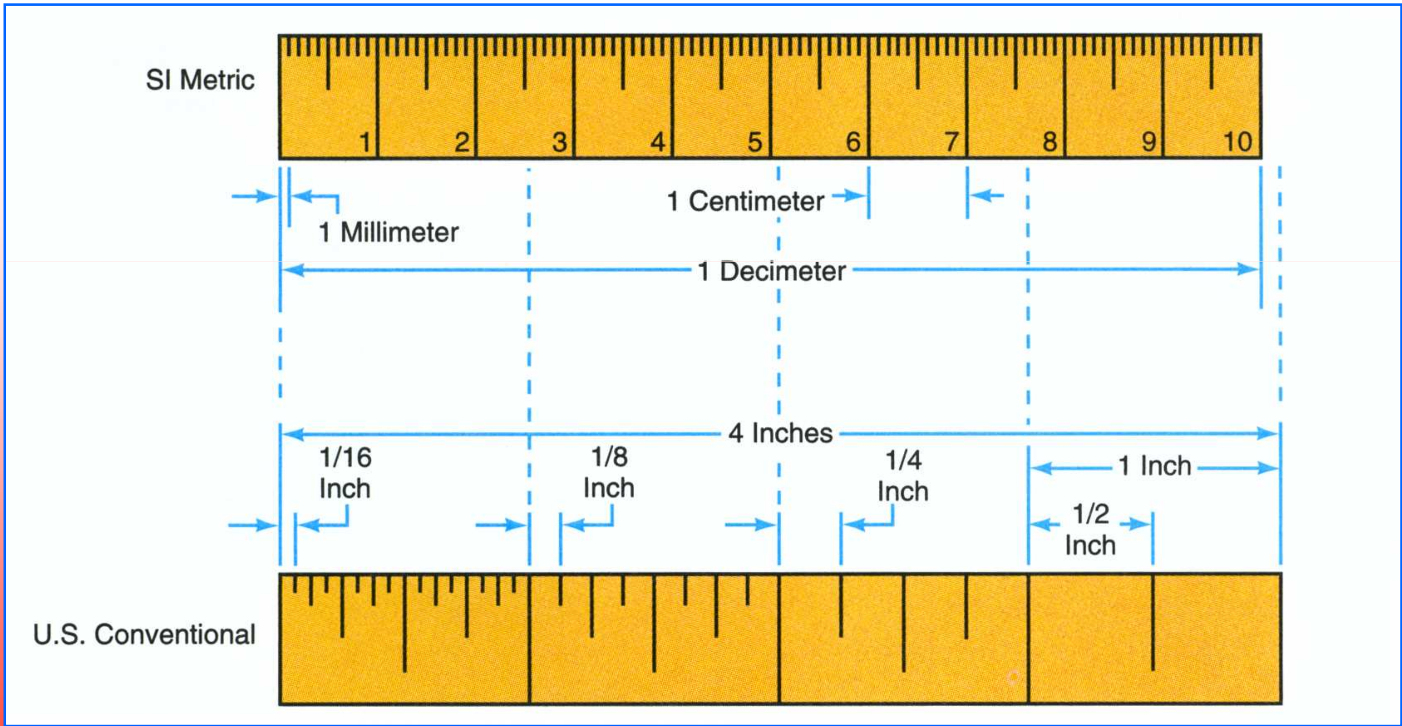
Linear Measurement

Metric Units and U.S. Conventional Unit Equivalents

1 millimeter (mm)	= 0.039 in.
10 mm	= 1 centimeter (cm) = 0.394 in.
10 cm	= 1 decimeter (dm) = 3.937 in.
10 dm	= 1 meter (m) = 100 cm
	= 39.37 in. = 3.28 ft.
1000 m	= 1 kilometer (km) = 3280.8 ft.
2.54 cm	= 1 in.

1.10.1

Linear Measurement



1.10.2

Area Measurement

Formula for measurement of an area.

Area (A) = Length (L) X Width (W)

1.10.2

Area Measurement

Area of a rectangle is calculated by measuring width by length.

Example:
The width of a tabletop is 2' and the length of the table is 4'. Determine the area of the tabletop.

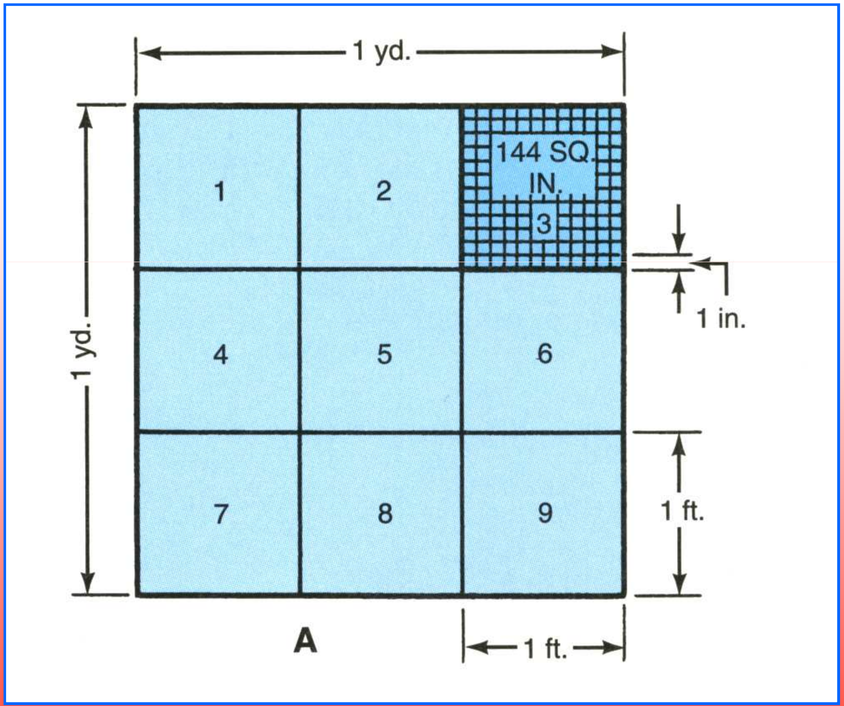
Solution:

Area (A)	**=**	**Length (L) X Width (W)**
A	**=**	**2' X 4'**
A	**=**	**8 sq. ft.**

The area of the tabletop is 8 sq. ft.

1.10.2

Area Measurement



Area Measurement

1.10.2

Formula for area of a circle.

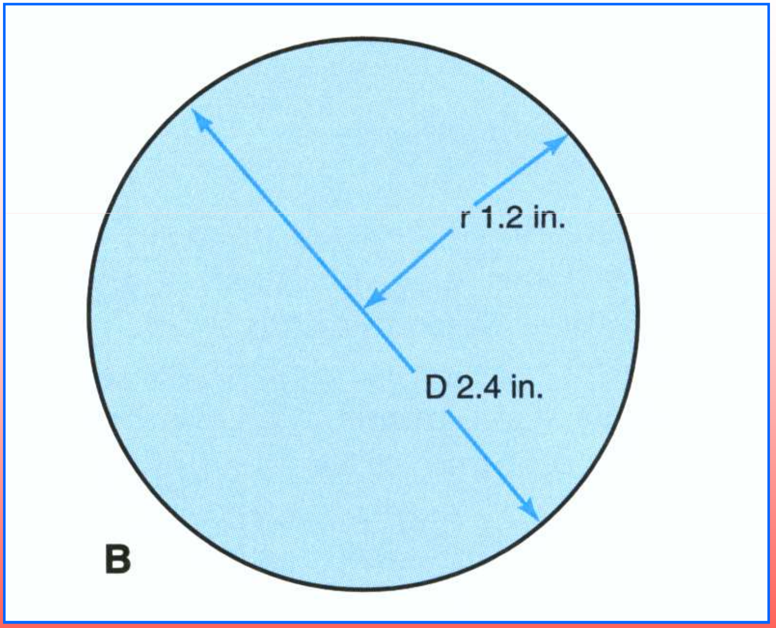
$$A = \frac{\pi D^2}{4}$$

or

$$A = \pi r^2$$

1.10.2

Area Measurement



1.10.2

Area Measurement

Area of a circle is calculated using the formula:

$$A = \pi r^2$$

Value of π is 3.1416. If the diameter of a circle is 2.4 in., the radius r (half the diameter) is 1.2 in.:

$r^2 = r \times r = 1.2 \times 1.2 = 1.44$.

Area of circle is 3.1416 X 1.44 = 4.52 in^2.

1.10.3

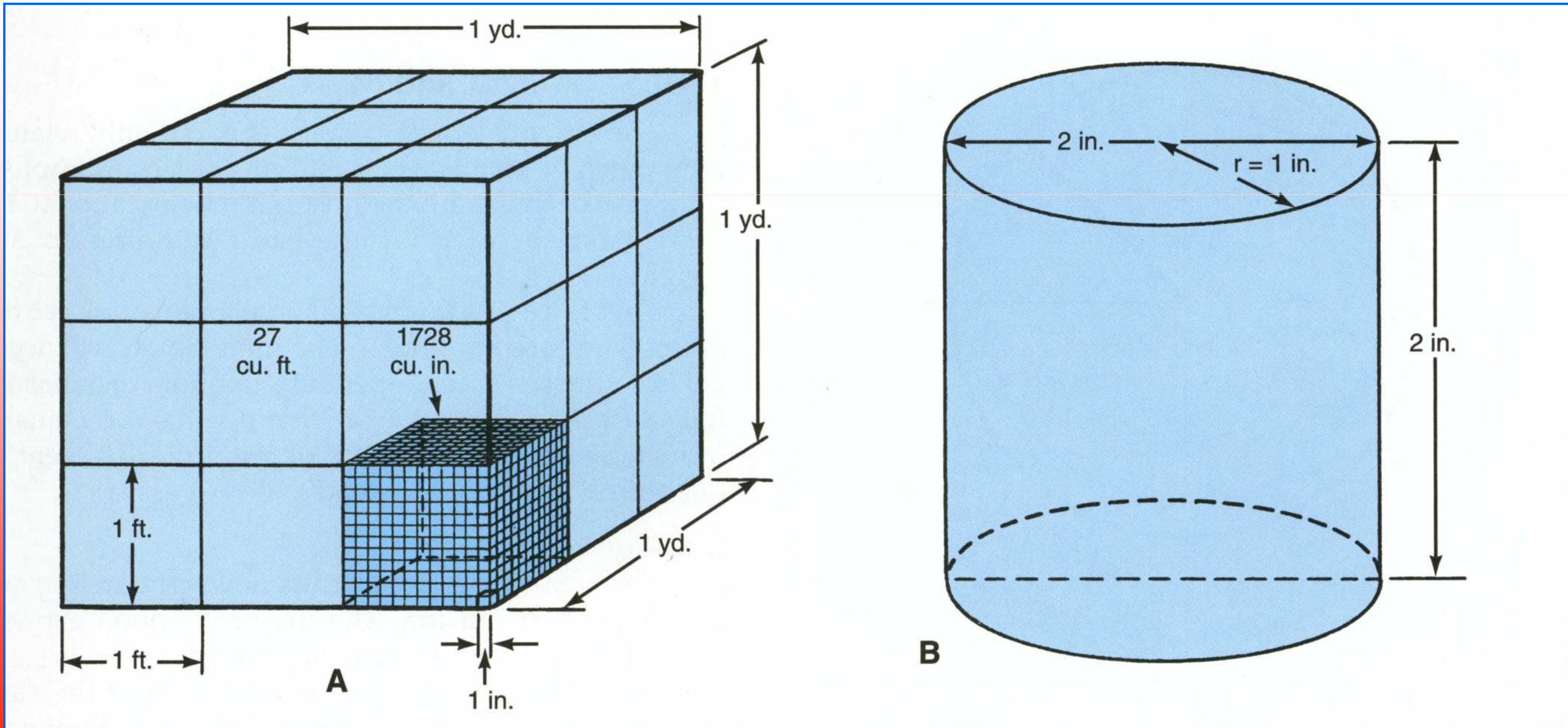
Volume Measurement

Formula for measurement of volume.

Volume = width (W) X length (L) X height (H)

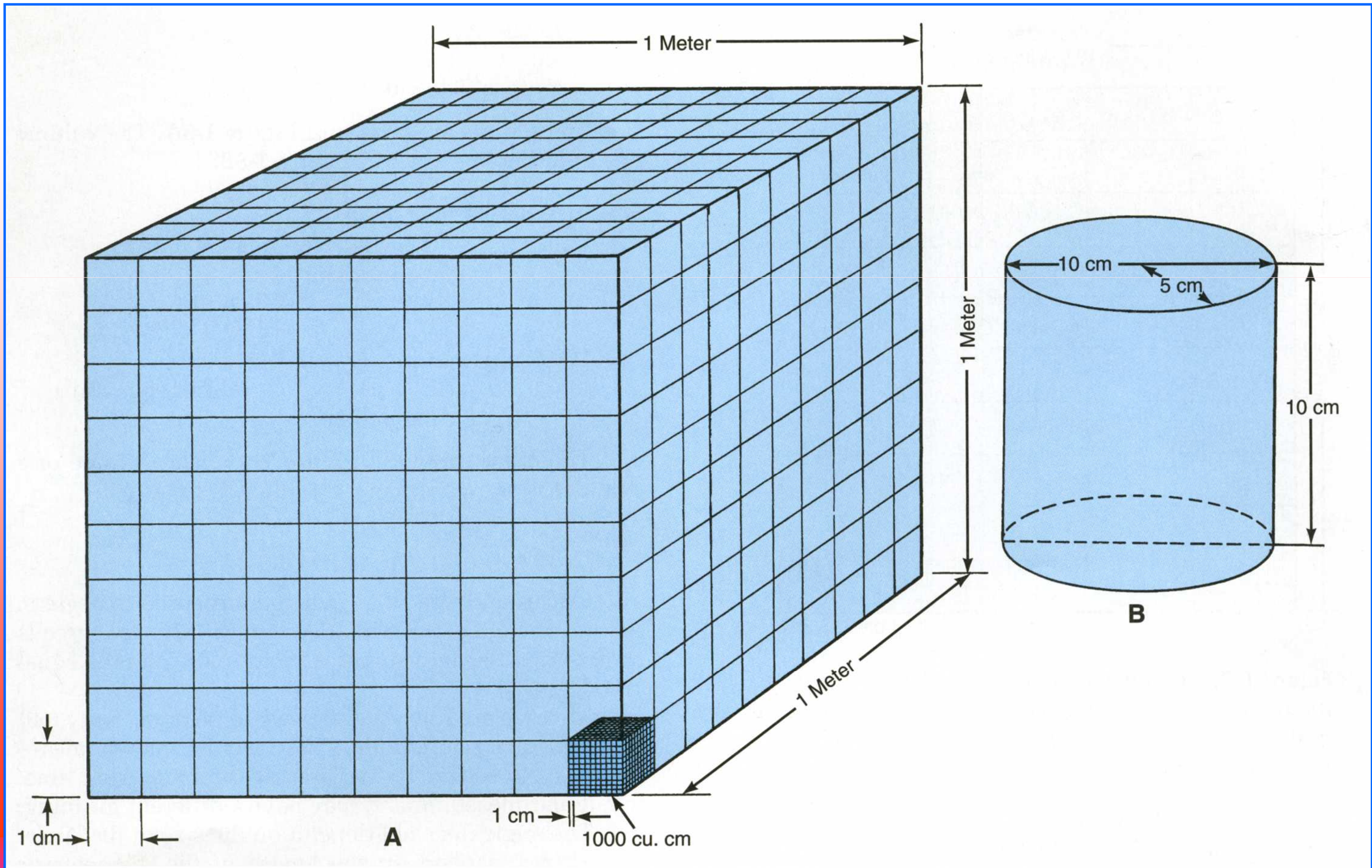
1.10.3

Volume Measurement



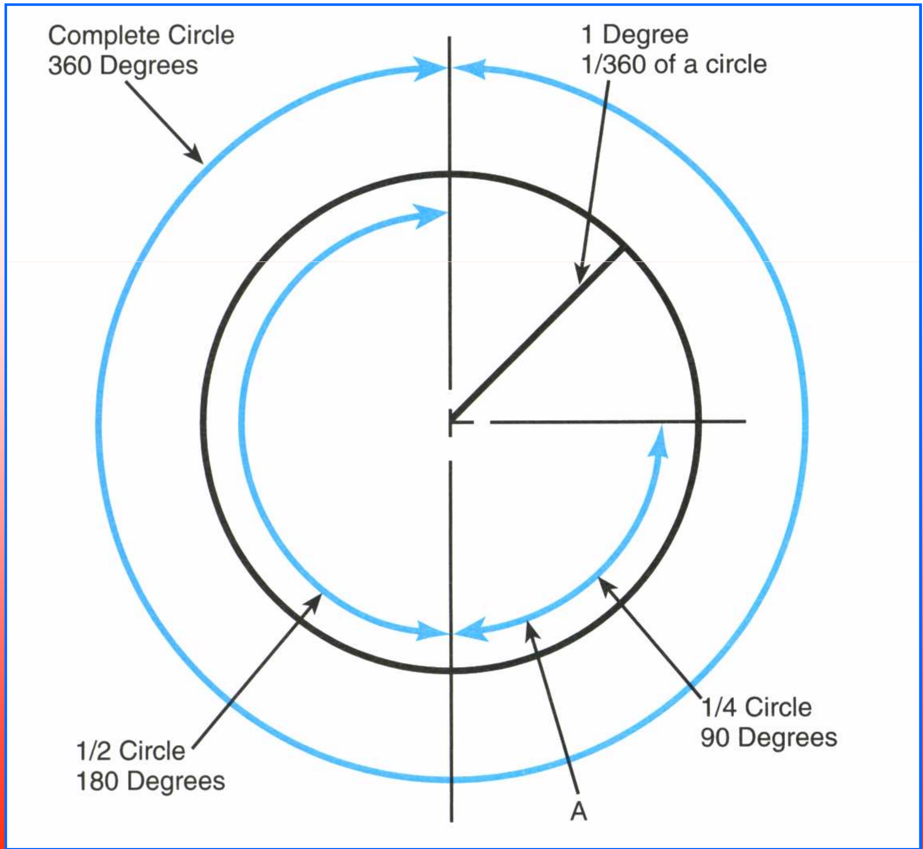
1.10.3

Volume Measurement



1.10.4

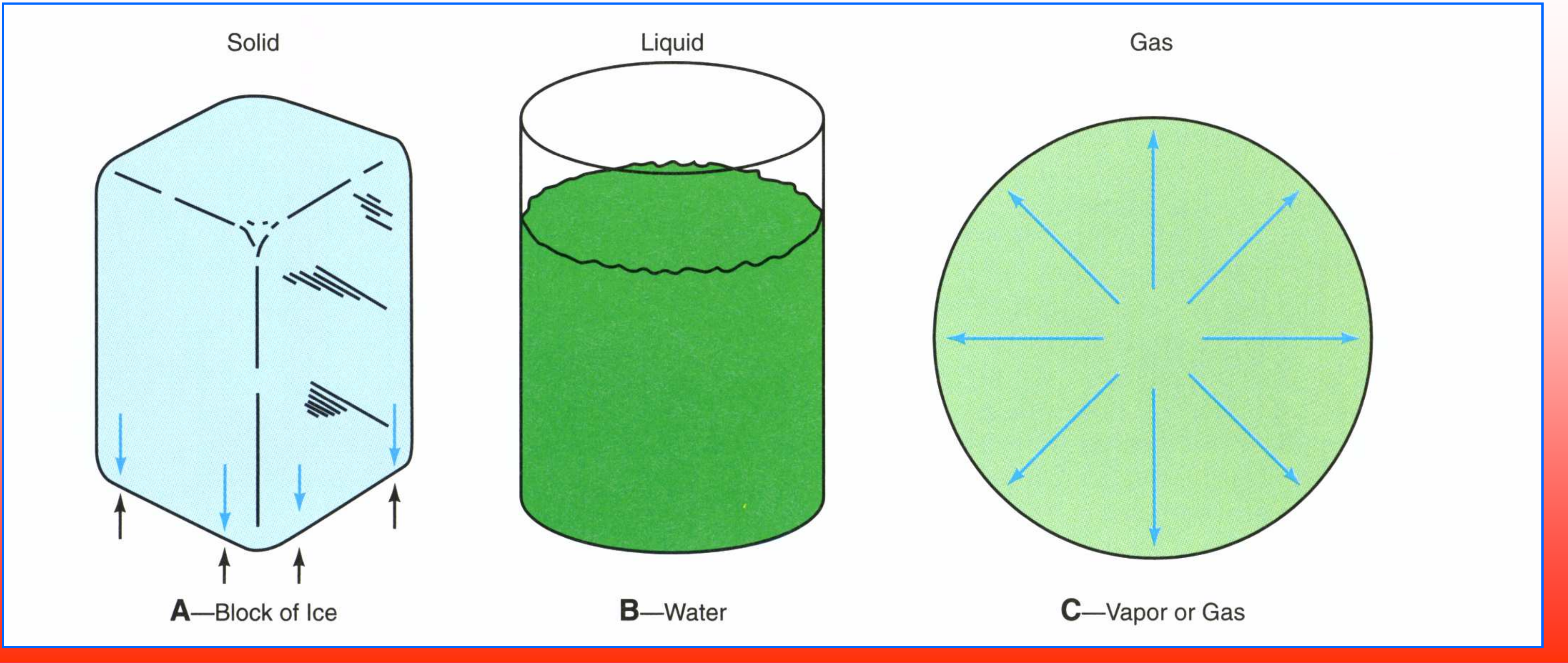
Angular Measurement



- **Circles and arcs of a circle are measured in degrees.**
- **A complete circle has 360°.**

Pressure

Pressure is expressed in pounds per square inch (psi), pascals (Pa), or kilopascals (kPa).



1.11.1

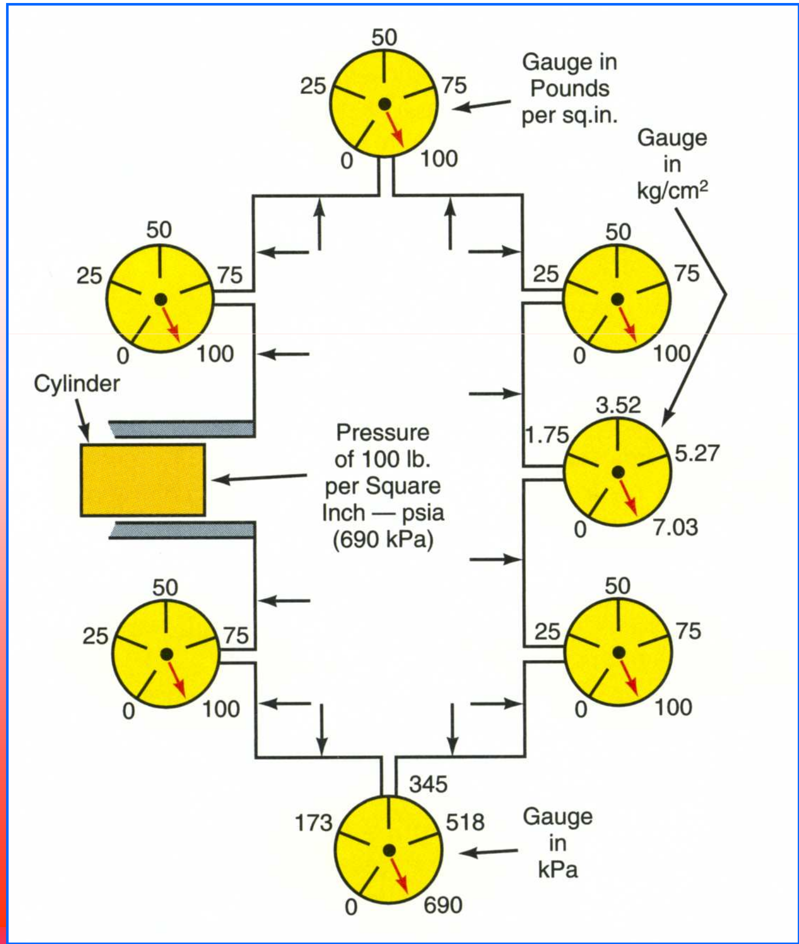
Pascal's Law

- **Pressure applied upon a confined fluid is transmitted equally in all directions. This is the basis of operation of most hydraulic and pneumatic systems.**
- **Refrigeration technicians deal with pressures above and below atmospheric pressure.**

1.11.1

Pascal's Law

- **Pressure of 100 psia (690 kPa) is pressing against a piston having head area of 1 sq. in.**
- **All gauges have same reading.**
- **Bottom gauge, calibrated in kilopascals, reads 690 kPa (100 psia).**



Pressures — Atmospheric, Gauge, and Absolute

1.11.2

- **Gauges are calibrated so that zero on the gauge indicates atmospheric pressure (14.7 psia). This compound gauge also allows vacuum readings (pressures that are below atmospheric) expressed as in. Hg.**

1.11.2

Pressures — Atmospheric, Gauge, and Absolute

continued

- U.S. conventional units measure pressures above atmospheric pressure in pounds per square inch (psi).
- U.S. conventional units measure pressures below atmospheric in inches of mercury (in. Hg) column.
- Atmospheric pressures are expressed in pounds per unit of area or in inches of liquid column height.
- Most commonly used gauges register in pounds per square inch above atmospheric pressure (psig or psi).
- A reading of 0 psi on the gauge is equal to the atmospheric pressure, which is about 14.7 psia.

Pressures — Atmospheric, Gauge, and Absolute

continued

1.11.2

- **Absolute pressure is gauge pressure plus atmospheric pressure.**

Example:

Calculate absolute pressure when the pressure gauge reading is 21 psi.

Solution:

Absolute pressure equals gauge pressure plus atmospheric pressure.

psi + 15 = 21 + 15 = 36 psia

1.11.2

Pressures — Atmospheric, Gauge, and Absolute

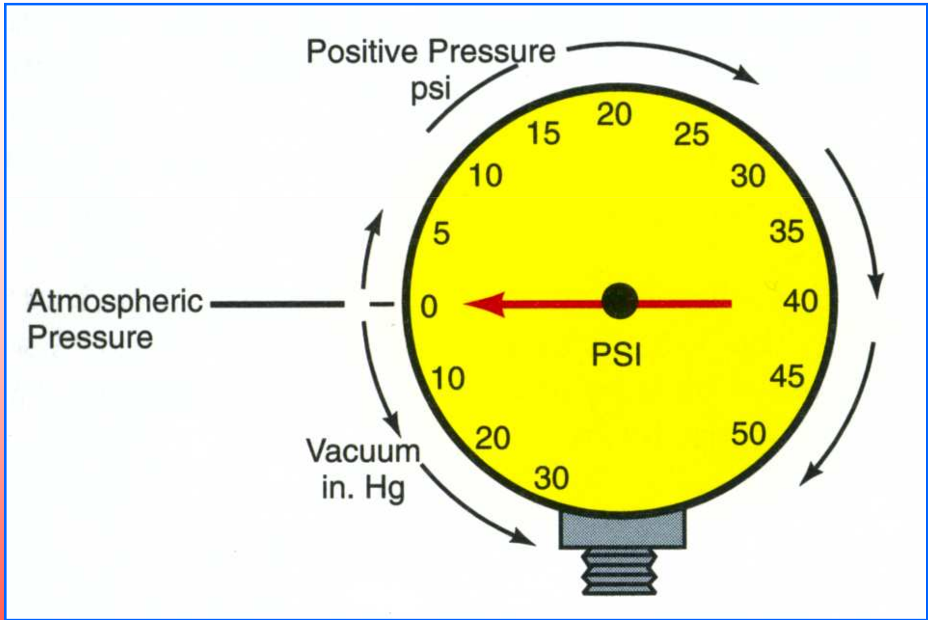
continued

A compound gauge usually has two pressure scales.

- **One measures pressure below atmospheric pressure.**
- **One measures pressure above atmospheric pressure.**

Pressures — Atmospheric, Gauge, and Absolute

1.11.2



Questions

- On the Fahrenheit scale, at what temperature does water freeze? 32 degrees
- On the Celsius scale, at what temperature does water boil? 100 degrees
- At what temperature are the Celsius and Fahrenheit scales equal? – 40 degrees
- What is the formula for the area of a rectangle?
  Length X Width X Height
- What is the formula for the area of a circle?
  πr^2 or $\pi \times D^2 / 4$

Questions

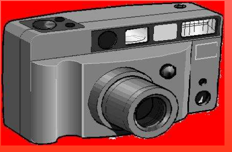
continued

- Which law states that the pressure on a confined fluid is transmitted equally in all directions? Pascal's Law
- To convert psia to psig, what must be done?
  Subtract 14.7 from psia
- Which gauge has two or more pressure scales?
  The compound gauge.

1.11.2

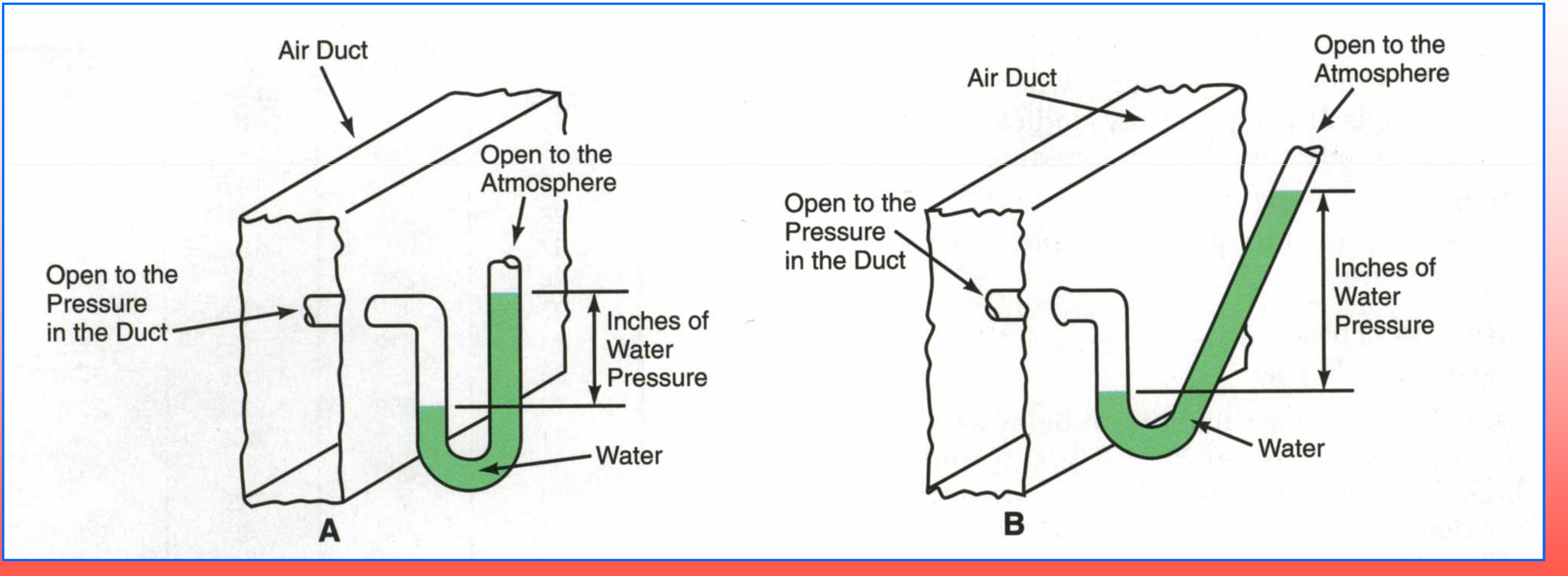
Manometer

- Used for measuring small pressures above or below atmospheric pressure.
- Frequently used for pressures in air ducts, gas lines, etc.
- A water column 2.3' high (or about 28") equals 1 psi.



1.11.2

Manometer



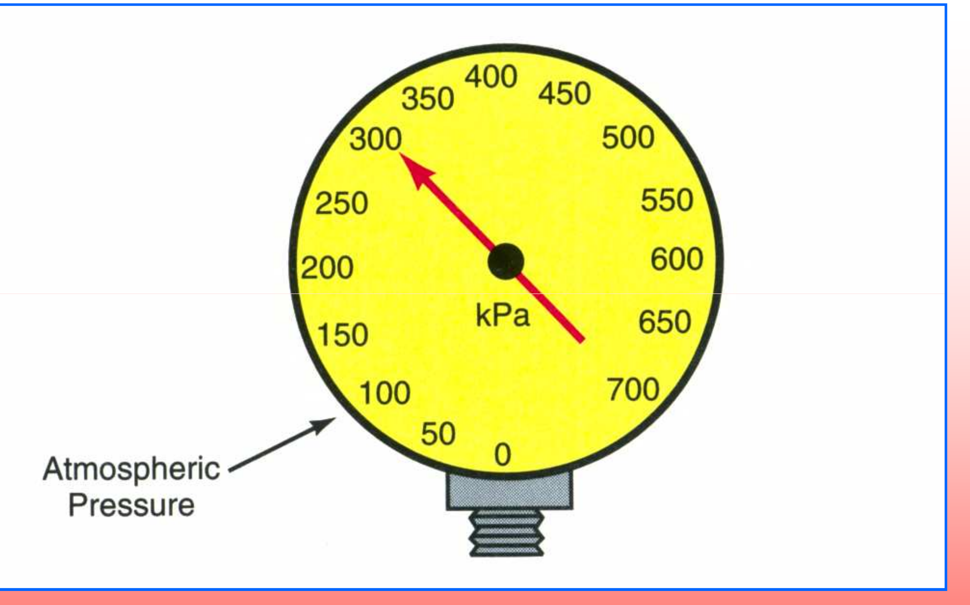
1.11.2

SI Metric Units

- **Partial vacuum: Pressure lower than atmospheric pressure (101.3 kPa).**
- **The pascal (Pa), rather than the kilopascal (kPa), is used for measuring high vacuums (pressures close to a perfect vacuum).**
- **Perfect vacuum: Zero on the absolute pressure scale (0 Pa); a pressure that cannot be further reduced.**

SI Metric Units

1.11.2



In SI units, atmospheric pressures are expressed in kPa (kilopascals). Normal atmospheric pressure is 101.3 kPa, but gauges are often calibrated at 100 kPa for atmospheric pressure for ease of use.

1.12

Three Physical States

- Substances can exist in three states. Their state depends on temperature, pressure, and heat content.
  - Solid — Any physical substance that keeps its shape even when not contained.
  - Liquid — Any physical substance that will freely take on the shape of its container.
  - Vapor — Any physical substance that must be enclosed in a sealed container to prevent its escape into the atmosphere.

Formulas for Force, Work, Energy, and Horsepower

- **Force = area of the piston head X pressure**

$$F = A \times P$$

Formulas for Force, Work, Energy, and Horsepower

1.15.1 & 1.15.2

continued

- **Work = Force X Distance**

W = F X D

1.17.1

Power

Horsepower =

$$\text{weight in pounds} \times \frac{\text{Distance in feet}}{\text{Time in minutes}} \times 33{,}000$$

1.18

Unit of Heat

- Btu: British thermal unit or the unit of heat.
- The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.
- Formula:

Btu = wt. in lb. X Specific Ht. X Temperature Change °F.

Unit of Heat

1.18

- Joule = In SI metric, the unit of heat.
- In refrigeration work, the kilojoule (kJ), 1000 joules, is used.
- The amount of heat required to raise the temperature of 1 kg of water 1°C is equal to 4.187 kJ.
- Formula

kJ = 4.187 X mass in kg X temperature change in °C

First Law of Thermodynamics

1.18.1

- Heat and mechanical energy are mutually convertible.
- The Btu is the unit of heat in U.S. conventional unit. The ft.-lb. is the unit of work. Work is convertible to heat. Since work is convertible to heat, the conversion factor from Btu to ft.-lbs. is used.
- Formula for U.S. conventional units:

$$1 \text{ Btu} = 778 \text{ ft.-lbs.}$$

1.18.1

First Law of Thermodynamics

continued

- **The joule is defined as the unit of heat in SI metric units. The unit of work is also the joule, or newton-meter.**
- **Example:**

100 joules of work = 100 joules of heat,
or 100 newton-meters.

1.18.2

Sensible Heat

- Heat that causes a change in temperature in a substance.
- When a substance is heated, the temperature rises.
- This increase in heat is called sensible heat.
- If heat is removed from a substance, the temperature falls.
- The heat removed is sensible heat.

Questions

- **What is the name of the gauge used to measure air and gas pressures?** The manometer.
- **What scale is most commonly used on the manometer?**
  Inches of water column.
- **What is the formula for force in a fluid?**
  Force = Area X Pressure
- **What is the formula for work?** Force X Distance
- **What is a Btu?**
  A British thermal unit (measurement of heat)

Questions
continued

- **What is a definition of Btu?**
  The amount of heat required to raise 1 pound of water 1°F.
- **What is the first law of thermodynamics?**
  Heat and mechanical energy are mutually convertible.
- **What is sensible heat?**
  The heat required to change the temperature of a substance.

1.18.3

Specific Heat Capacity

- **In U.S. conventional units, specific heat capacity is the amount of heat added or released to change the temperature of one pound of a substance by 1°F.**
- **In SI metric units, the specific heat capacity of a substance is the amount of heat that must be added or released to change the temperature of one kilogram of substance by 1°K (Kelvin).**
- **Different substances require different amounts of heat per unit mass to cause changes of temperature.**

Specific Heat Capacity

continued

- **Formula for specific heat capacity of U.S. conventional units or SI metric units:**

Heat added or removed = Mass substance X Specific heat substance X Change in temperature

$$Q = M \times \text{sp. Ht.} \times \Delta T$$

1.18.3

Specific Heat Capacity

Material	Specific Heat Capacity	
	Btu/lb./F	kJ/kg•K
Wood	0.327	1.369
Water	1.0	4.187
Ice	0.504	2.110
Iron	0.129	0.540
Mercury	0.0333	0.139
Alcohol	0.615	2.575
Copper	0.095	0.398
Sulphur	0.177	0.741
Glass	0.187	0.783
Graphite	0.200	0.837
Brick	0.200	0.837
Glycerine	0.576	2.412
R-717 (Liquid ammonia at 40 °F)	1.1	4.606
R-744 (Carbon dioxide at 40 °F)	0.6	2.512
R-502	0.255	1.068
Salt Brine 20%	0.85	3.559
R-12	0.213	0.892
R-22	0.26	1.089

The above values may be used for computations which involve no "change of state." If a change of state is involved, the specific heat for each state of the substance must be used.

Specific heat capacity values for some substances.

1.18.4

Latent Heat

- Heat that brings about a change of state with no change in temperature.
- Every substance has a different latent heat value. 
- All pure substances are able to change state.
- The addition of heat or the removal of heat produces these changes. 

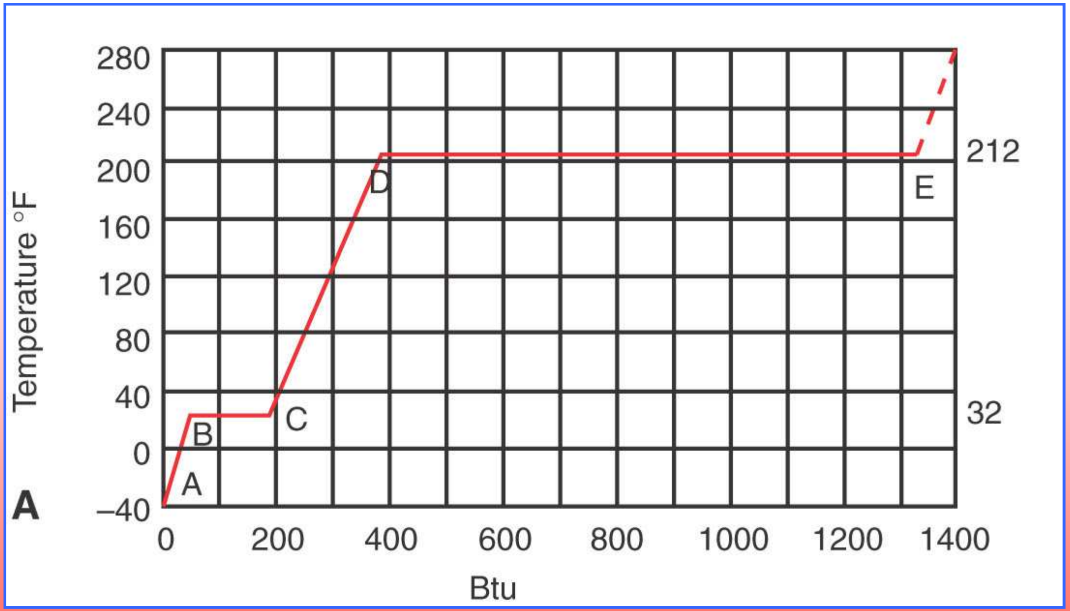
1.18.4

Latent Heat

Material	Freezing or Melting Btu/lb.	Latent Heat of Vaporization or Condensation Btu/lb.	Freezing or Melting kJ/kg	Latent Heat of Vaporization or Condensation kJ/kg
Water	144	970.4 at 212°F	335	2257 at 100°C
R-717 (Ammonia)	–	565.0 at 5°F	–	1314 at –15°C
R-502	–	68.96 at 5°F	–	160 at –15°C
R-40 (Methyl chloride)	–	178.5 at 5°F	–	415 at –15°C
R-12	–	68.2 at 5°F	–	159 at –15°C
R-22	–	93.2 at 5°F	–	217 at –15°C

1.18.4

Latent Heat



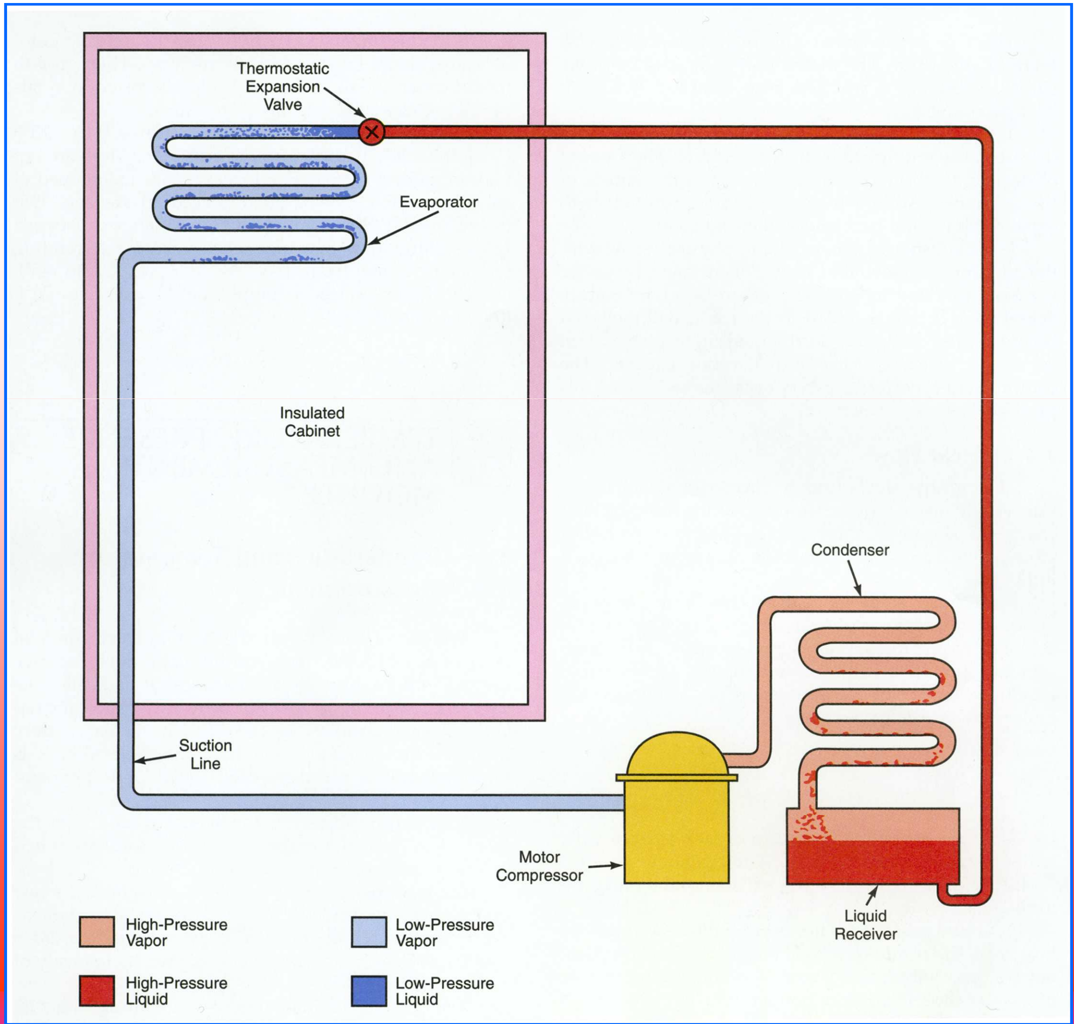
1.18.5

Basic Refrigeration Cycle

- In a refrigerator, freezer, or air conditioner, liquid refrigerant is piped under pressure to the evaporator.
- In the evaporator, the pressure is greatly reduced.
- The refrigerant boils (vaporizes), absorbing heat from the evaporator.
- This produces a low temperature and cools the evaporator.

1.18.5

Basic Refrigeration Cycle



1.18.5

Basic Refrigeration Cycle

continued

- **The compressor pumps the vaporized refrigerant out of the evaporator.**
- **It compresses the refrigerator into the condenser.**
- **Heat that was absorbed in the evaporator is released to the surrounding atmosphere.**

Ambient Temperature

- **The temperature of the air surrounding a device.**
- **Ambient temperature is not usually constant.**

1.23

Heat of Compression

- As a gas is compressed, its temperature rises. This is due to the work (energy) added to the gas by the compressor. The energy added is termed heat of compression.
- The compressed vapor in the condenser is much warmer than the surrounding air. The heat of compression is rapidly transferred through the condenser walls to the surrounding air.

Questions

- **What is specific heat?**

  The amount of heat required to change the temperature of 1 pound of a substance by 1°F.

- **What is latent heat?**

  The heat required to change the state of a substance, also known as hidden heat.

- **What are the four main components of a basic refrigeration cycle?**

  Compressor, condenser, metering device, and evaporator.

Questions
continued

- What part of the refrigeration cycle is under low pressure and changes the refrigerant from a liquid to a gas?

  The evaporator.

- What state is the refrigerant as it goes through the compressor? A gas.

- What is ambient temperature?

  The temperature of the air that surrounds a device.

Questions

continued

- **What happens to the temperature of a gas as it is being compressed?** Its temperature increases.
- **Which part of the refrigeration system changes the refrigerant from a high-pressure gas to a high-pressure liquid?** The condenser.

REFRIGERATION SYSTEMS AND TERMS MODULE

Refrigerant

- Fluid that absorbs heat inside the cabinet and releases it outside.

Heat Transfer

- Occurs by one of the following means:
  - Radiation —Transfer of heat by heat rays.
  - Conduction —Flow of heat between parts of a substance by molecular vibrations.
  - Convection —Movement of heat from one place to another by way of a fluid, liquid, or gas.

Brine and Sweet Water

- Salt, either sodium chloride (NaCl), or calcium chloride ($CaCl_2$), is added to water to form brine:
  - Raises the temperature at which water will boil.
  - Lowers the temperature at which water will freeze.
  - Refrigerating and air conditioning systems using tap water without salt or other substances added are referred to as “sweet water" systems.

Dry Ice

- Solid carbon dioxide (CO_2) or “dry ice:"
  - Remains at a temperature of –109°F (–78°C) while in a solid state at atmospheric pressure.
  - Does not change into a liquid. It changes directly from solid to vapor.
  - Has a greater heat-absorbing capability than water ice.

1.28

Dry Ice

continued

CAUTION:

- **Never place dry ice in a sealed container!**
- **Avoid touching dry ice! It will instantly freeze the skin!**

Enthalpy

- **All the heat in one pound of a substance, calculated from an accepted reference temperature (32°F).**
- **This reference temperature (32°F) is used for water and water vapor calculations.**
- **–40°F is the reference temperature for refrigerant calculations.**
- **Formula:**

$$H = M \times sp.\ Ht. \times \Delta T$$

Enthalpy

continued

- **SI Metric uses:**
  - **0°C enthalpy for water**
  - **–40°C and 100 kPa for refrigerants**
  - **25°C and 100 kPa for air**

1.31.1

Specific Enthalpy

- **Measured in Btu per pound (J/kg)**
- **Formula:**

$$h = H/M$$

(Specific enthalpy = Enthalpy absorbed/Mass)

Cryogenics

- Applies to the use of liquid helium, nitrogen, and liquid hydrogen in refrigeration.

Perfect Gas Equation

- **Describes the relationship between pressure, temperature, and volume if a quantity of gas were enclosed in a tightly sealed container.**
- **Formula:**

$$PV = MRT$$

Note: Same formula is used with SI metric units.

- **Shows that if container is heated, both temperature and pressure will increase. Cooling a container will reduce both the temperature and pressure.**

Dalton’s Law

- The total pressure of a confined mixture of gases is the sum of the pressures of each of the gases in the mixture.
- The total pressure of the air in a compressed air cylinder is the sum of the oxygen, nitrogen, and carbon dioxide gases, and the water vapor pressure.
- Each gas behaves as if it occupies the space alone.

Evaporator

- **Refrigeration system component in which the refrigerant boils or evaporates and absorbs heat.**

Vapor

- **Refrigerant that has become heated, usually in the evaporator, and changed to a vapor or gaseous state.**

Saturated Vapor

- **Condition of balance in an enclosed amount of vaporized fluid.**
- **If temperature or pressure lowers, condensate (liquid) will be produced.**

Humidity

- Water vapor or moisture in the air.
- The higher the temperature of the air, the more moisture it will absorb.

Relative Humidity

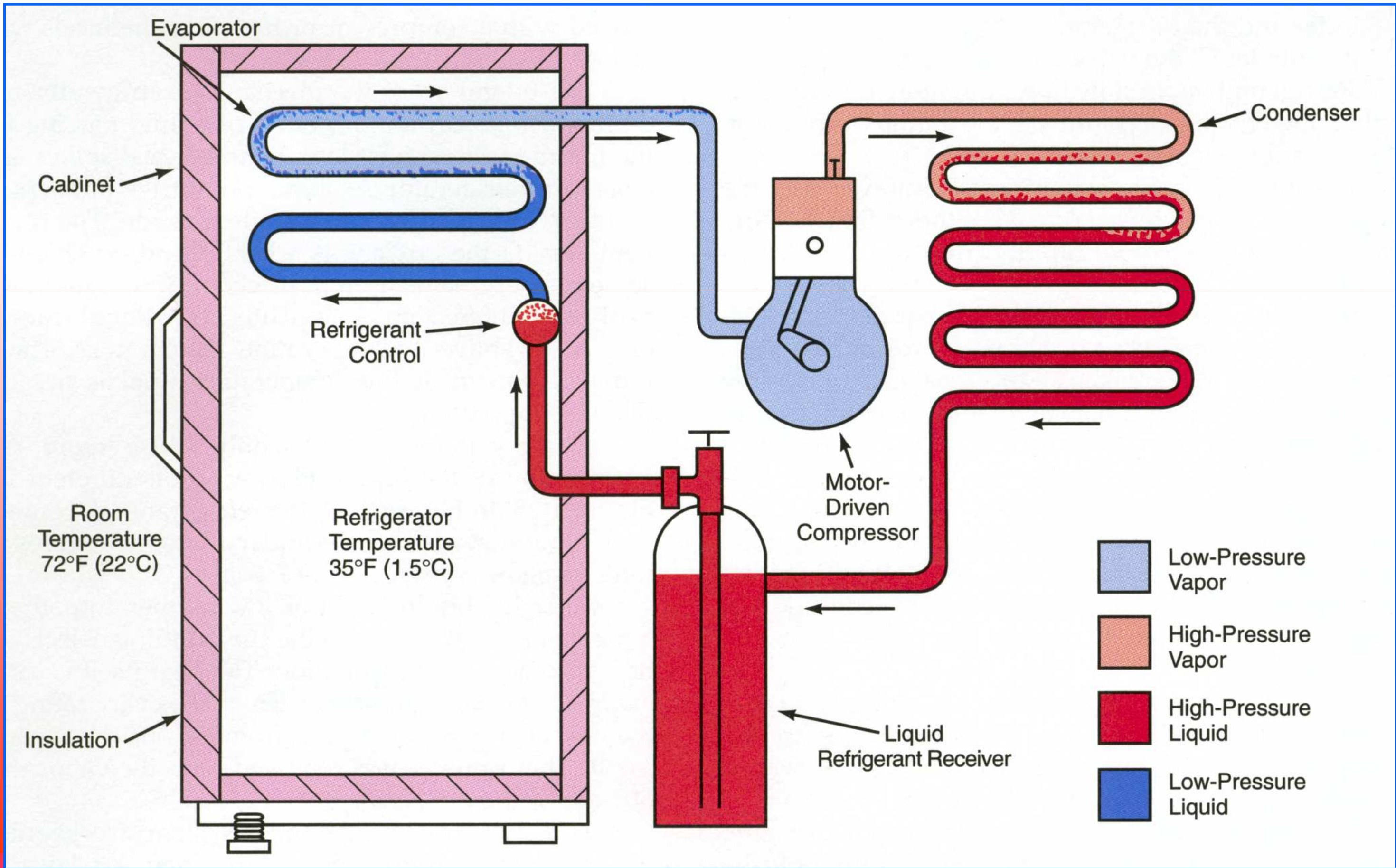
- **The amount of moisture carried in a sample of air, compared to the total amount it is capable of absorbing at the stated pressure and temperature.**

Mechanical Refrigerating System

1.39

- **Captures vaporized refrigerant, compresses it, and cools it to a liquid state again.**

Mechanical Refrigerating System



Questions

- **What are three methods of heat transfer?**

  Radiation, conduction, and convection.

- **What happens to the freezing point of water when sodium chloride or calcium chloride is added?**

  It lowers the freezing point.

- **What compound makes dry ice?**

  CO_2 (carbon dioxide).

Questions

continued

- **Name three cryogenic refrigerants.**

  Helium, nitrogen, and hydrogen.

- **Which law states that the total pressure of a confined mixture of gases is the sum of the pressures of each of the gases in the mixture?** **Dalton's Law.**

- **What is meant by the term, saturated vapor?**

  Vapor that is in the presence of a liquid.

Questions

continued

- **Will warm air, or cold air, absorb more moisture?**
  Warm air.
- **Which part of the refrigeration system lowers a high-pressure, high-temperature liquid to a low-pressure, low-temperature liquid?** **The metering device.**

Safety

- Always disconnect the circuit from the power source when working on electrical circuits.
- Be sure all connections are tightened before operating a compressor.
- Before operating an open compressor, be sure flywheel and pulley are aligned and guards are in place.
- Always observe proper operating temperatures for units.

Glossary

- **Btu**
  British thermal unit, the unit of heat used in the conventional system.
- **Celsius**
  Temperature scale used in metric system.
- **Fahrenheit**
  Temperature scale under standard atmospheric pressure.
- **heat**
  Form of energy that acts on substances to raise their temperature; energy associated with random motion of molecules.

Glossary

- **Joule**

  The unit of heat in the SI metric system.

- **pressure**

  Energy impact on a unit area; force or thrust on a surface.

- **temperature**

  Degree of hotness or coldness as measured by a thermometer or the measurement of the speed of molecular motion.