SAULT COLLEGE OF APPLIED ARTS & TECHNOLOGY

SAULT STE. MARIE, ONTARIO

COURSE OUTLINE

Course Title: PHYSICS

Code No.: PHY 109-3

Program: MECHANICAL

Semester: THREE

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New: Revision

APPROVED ~~~~~~~~ ^h ~DS'/6

Chairperson Date

PHYSICS
Course Name

PHY 109--3
Course Number

PHILOSOPHY/GOALS:

SEE NEXT PAGE

METHOD OF ASSESSMENT (GRADING METHOD):

There are four topics of study. Each topic will be tested about one week after its conclusion. Notice will be given at least one week prior. The following list indicates the relationship between numerical test scores and letter grades:

A = 80-100%

B = 65- 79%

C = 55- 65%

TEXTBOOK(S):

None required

PHYSICS 109-3

GENERAL OBJECTIVES:

The objectives of this course reflect the prerequisites for subsequent courses in Thermodynamics and heat offered in the Mechanical Technology program.

The objectives, in general statements, are as follows:

1. The course provides a foundation of the fundamental principles of Heat and Thermodynamics, with practical application through problems.

2. The course requires the student to learn and apply the units in both Imperial and S.I. systems.

SUMMARY OF TOPICS

Topic 1. Concepts of Heat, Temperature and Internal Energy

Topic 2. Thermal Properties of Matter

Topic 3. The Fundamental Laws of Thermodynamics

Topic 4. The Mechanisms of Heat Transfer

Topic #1

Content - Concepts
Historical Sketch
Heat, Temperature and Internal Energy
Temperature Metrology
The Temperature Scales
The Relationship Between Work and Heat
Specific Heat of Solids and Liquids
Changes of State
The Processes of Evaporation and Condensation
The Processes of Melting and Freezing
The Processes of Regelation and Sublimation
Humi d1ty

Topic #2

Content- Thermal Properties
Structure of Matter

Summary of Topics**.continued

Topic #2,,.continued

Thermal Expansion of Solids and Liquids
The Relationship Between Thermal Expansion and Deformation
Due to Stress
Linear Expansion and Volumetric Expansion
Kinetic Theory of Gases
Charle's and Boyle's Laws
Ideal Gas Law
Molecular Energy and Boltzmann's Constant
Molecular Motion in Liquids

Topic »3

Laws of Thermodynamics
The Characteristics of Heat Engines
The First Law of Thermodynamics
The Second Law of Thermodynamics
The Carnot Engine
Carnot Efficiency
Real Engines

Topic #4

Heat Transfer
Conduction
Convection
Radiation
The Refrigerator-Neat Pump
The Air Conditioner

SPECIFIC OBJECTIVES AND PROBLEM SETS

Topic #1

The student will be able to:

1. Explain the origin and meanings of such terms as caloric, frigoric, photgiston, and explain the work of Count Rumford.

2. Define "internal energy", heat and temperature.

3. Explain how the electrical, magnetic and optical properties of matter can be exploited in the metrology of heat.

4. Sketch and describe the following:
   a) The Liquid Thermometer
   b) The Bimetal Strip
   c) The Constant Volume Gas Thermometer

5. Describe a procedure for calibrating a liquid thermometer by utilizing the freezing and boiling temperatures of water.

6. Using the changes of state temperatures of water, differentiate between the Celsius and Fahrenheit thermometer scale readings.

7. Define the Kilojoule and the British Thermal Unit.

8. Define the units:
   a) Newton
   b) Pound Force
   c) Newton Meter
   d) Pound Foot

9. Define: a) Kinetic Energy; b) Potential Energy

10. State the relationship between B.T.U.'s and ftlbf.

11. Define Specific Heat of a Substance.

12. State the specific heat of ice, water, and steam, in both Imperial and S.I. systems.

13. State the formula relating heat transferred, specific heat, mass and change in temperature.

14. Explain the likely mechanisms that take place at the molecular level when matter freezes and melts, vapourizes and condensation.

15. Define the Heat of fusion and the Heat of vapouriration.

16. State the values of the heats of fusion and vapourization in both systems. Imperial and S.L

17. Draw the triple point diagram for water, labelling all parts.

18. Explain, using the triple point chart, how boiling and freezing can occur simultaneously.

19. Define sublimation.

20. Define regilation and provide an example.

21. Define: a) Absolute Humidity b) Relative Humidity

22. Answer completely and correctly the following questions and problems:

Topic #1, Part 1

QUESTIONS OF A CURIOUS NATURE

1. Why does a piece of metal become warm when struck with a hammer?

2. Distinguish between Internal Energy and heat.

3. Define temperature.

4. What is the lowest possible Celsius temperature? Kelvin temperature?

5. Why does "Because different substances have different specific heats" not answer the question "Why do some substances increase in temperature more than other substances for the same absorbtion of heat?" What is the correct answer?

6. Why do material things generally expand when their temperature is increased?

7. Why does 1ce contract as its temperature is increased?

8. Why is water a better coolant in California than antifreeze?

9. At what temperature in degrees Kelvin is water the most dense?

10. Why is ice less dense than water?

11. Why does Lake Superior usually remain unfrozen in winter?

12. Is there any difference between the temperatures of the water in the crest of a falls and the water at the bottom (assuming no heat in or out from the surroundings)? What about the difference in temperature between water at the crest, and after it has fallen part way?

13. Why does the pressure of a gas which is rigidly enclosed, increase as the temperature increases?

14. Would you or the gas company gain financially by having the gas warmed before it passes through your meter?

15. What was the precise temperature at the bottom of Lake Superior 12:01 a.m. on October 31, 1894?

16. A piece of metal has a temperature of O'C. It is heated until it is twice as hot. What is its final temperature?

17. Suppose that water is used in a thermometer instead of mercury. If the temperature is really 4''C and then changes, why can't the thermometer indicate whether the temperature is rising or falling?

18. The desert sand is *very* hot during the day but very cool at night. What do we assume about its specific heat.

19. If cooling of a pond occurred at the bottom instead of the top, would a lake freeze from the bottom up? Explain.

20. If the specific heat of water were lower, would ponds be more of less likely to freeze in the late fall?

21. Explain why evaporation is a cooling process, and condensation is a warming process.

22. Do you feel less chilly if you dry yourself in a humid area after you shower? Explain.

23. Can a substance receive heat without undergoing a change in temperature?

24. Explain the difference between evaporation and boiling.

25. Explain why the temperature at which boiling occurs depends upon pressure.

26. Why is a pressure cooker more desirable to have when cooking in the mountains than cooking at sea level?

27. Boiling is a cooling process. Does this mean that to cool your hands you should place them in boiling water? Why not?

28. How can water both boil and freeze at the same time?

29. At what temperature and pressure does boiling and freezing occur?

30. Why does adding antifreeze to water lower the temperature at which freezing takes place?

31. When water freezes, is energy absorbed or released by the water.

32. When ice melts, is energy absorbed or released by the ice?

33. Is the food compartment in a refrigerator cooled by the vapourization of the refrigerant?

34. Why will warmer air support a greater amount of water vapour?

35. Why does water vapour in the air condense when the air is chilled?

36. What is the difference between absolute and relative humidity?

37. On cold days, frost forms on the inside of your windows- Why?

38. Can you give two reasons why blowing over hot soup tends to cool it?

39. Can you explain why pouring a cup of hot coffee into the saucer results in irore rapid cooling?

40. Would evaporation be a cooling process if all the molecules in a liquid had the same speed? Explain.

41. Death Valley motorists carry water in slightly porous canvas bags slung to the outside of their fast-moving automobiles. Explain.

41. Why does the temperature of boiling water remain the same as long as the heating and boiling continues.

42. Why does the temperature of boiling water remain the same as long as the heating and boiling continues.

43. Water will boil spontaneously in a vacuum. Could you cook an egg in this water on the moon?

44. In a nuclear submarine, the pemperature of the water in the reactor is above 100"C. How can this be?

45. Why is it that on a cold winter's night, a tub of water placed in a farmer's canning cellar helps to prevent freezing of the canned goods?

46. The human body can maintain its customary temperature even during a day at 40"C temperature. How does it accomplish this feat?

47. Why are icebergs often surrounded by fogs?

48. Explain the formation of dew found on the grass in early morning.

49. Why does a dog pant?

Topic #1, Part 2

Multiple Choice

1. Heat is most closely related to:
   a) temperature
   b) friction
   c) energy
   d) momentum

2. Two thermometers, one calibrated in Celsius and the other in Fahrenheit are used to measure the same temperature.
   The numerical reading on the Fahrenheit scale is:
   a) proportional to that on the Celsius thermometer.
   b) greater than that on the Celsius thermometer.
   c) less than that on the Celsius thermometer.
   d) greater or less than that on the Celsius thermometer.

3. Oxygen boils at -183'C. This corresponds with:
   a) -215'F
   b) -297'F
   c) -329''F
   d) -361°F

4. A temperature of 100'*F is almost exactly:
   a) 38'C
   b) 122°C
   c) Se'C
   d) 212°C

Two blocks of lead, one twice as heavy as the other are both at SO'C. The ratio of the internal energy of the heavier block to the lighter is:
a) *h*
b) 1: 1
c) 2: 1
d) 4: 1

6. The quantity of heat required to change the temperature of a unit mass of a substance 1 degree is called:
a) specific heat capacity
b) heat of fusion
c) the mechanical equivalent
d) the heat of vaporization

?• Rank the following in descending order of ability to hold internal energy:
a) copper
b) ice
c) water
d) steam

8, A spoon of which material would be most effective in cooling coffee?
a) aluminum
b) copper
c) iron
d) silver

9, Body A is at a higher temperature than Body B, When placed in contact, heat will flow from A to B.
\- a) only if A has greater internal energy
b) only if both are miscible fluids
c) only if A is beneath B
d) until both have the same temperature

10. When vapour condenses it:
a) absorbs heat
b) evolves heat
c) temperature rises
d) temperature drops

11• Sublimation refers to:
a) the vaporization of a solid without first becoming a liquid
b) the melting of a solid
c) the vaporization of a liquid
d) the condensation of a gas to a liquid

12. Ten pounds of ice at O^F are added to 100 lbs. of water at SO'^F. The resulting temperature is:
    a) 19"F
    b) *32"?*
    c) *2Vf*
    d) 33"F
13. Ten kg. of ice at 0'*C is added to 2 kg. of steam at lOO'C. The resulting temperature is:
    a) 0"C
    b) 23"C
    c) 28^*0
    d) 40"C
14. One kg of lead at 80*C is placed in 2 kg of water at 20°C, the final temperature of the lead is:
    a) 22'C
    b) 28'C
    c) 40°C
    d) 50^*0
15. Twenty lbs of punch of specific heat 0.7 and at 40**F is placed in a 10 lb. silver bowl at 70°F. The final temperature of the punch is:
    a) 4rF
    b) *szy*
    c) 52'F
    d) 69'F
16- A 61 kg woman eats a banana whose energy content is 418 kJ. If this energy were used to raise her above the ground how high would she be above her present position? PE=mgh
    a) 0.7 m
    b) 70 m
    c) 7 m
    d) 700 m
17. A substance at its triple point is;
    a) in the solid state
    b) transisting to liquid
    c) transisting to vapour
    d) in all above states
    e) in any of the above states

EXERCISES

1. The melting point of lead is 330'C and its boiling point is 1170'C. Convert the temperatures to:
   a) degrees Kein
   b) degrees Fahrenheit
   c) degrees Rankin

2. The normal temperature of the human heat machine is 98.6°F- Determine this temperature in degrees Celsius.

3. At what temperature would Celsius and Fahrenheit readings be the same?

4. Two lb. of water is to be heated from 70*F to 212'F to make coffee. How much heat must be transferred to the water?

5. A 60 kg woman requires only 2500 keal daily. If a corresponding amount of energy were added to 60 kg of water at 37*^ what would the resulting temperature be?

6. How much heat must be added to 400 lb of iron to raise its temperature from SO'^F to 350"F?

7. How much heat must be removed from 60 lb of ice at 20'F to lower its temperature to -20**F?

8. How much heat must be added to 0.001 kg of silver to raise its temperature from -5 C to 65°C?

9. Eight BTU of heat is added to a 10 lb. copper bar at 60''F. Find its final temperature.

10. A 0-6 kg copper container holds 1.5 kg of water at 20*C. A 0.1 kg iron ball at 120°C is dropped into the water. Find the final temperature of the water.

11. A 0.1 kg piece of silver is taken from a bath of hot oil and placed in a 0.08 kg glass jar containing 0,2 kg of water at 15*'C. The temperature of the water increases by 8°C, What was the temperature of the oil?

12. How many kilo joules per hour are evolved by a 60 watt light bulb?

13. A 60 lb storage battery has an average specific heat of 0.2 BTU/lb'F. When fully charged, the battery contains lO^ft lb of electrical energy. If all this energy were dissipated within the battery, find the increase in temperature that would occur.

14. A 1 kg block of ice at 0℃ falls into a lake whose water is also at 0°C, and 0.01 kg of ice melts. From what minimum altitude did the ice fall?

15. If all the heat lost by 1 kg of water at 0℃ when it turns to ice at 0*℃ could be turned into kinetic energy, what would the velocity of the ice be?

16. The minimum velocity of an artificial earth satellite can have 7.9 x 10 m/s. Aluminum melts at GGCC. If an aluminum satellite re-enters the earth's atmosphere when its temperature 1s 0**C, can it be brought to rest rapidly by air resistance without melting? If not, how is this dilemma resolved in facts?

17. A lead bullet at lOO'C strikes a steel plate and melts. What was its minimum velocity?

18. A 100 kg wooden beam Is pushed across a stone floor by a force sufficient to maintain a constant speed. If the coefficient of friction is 0.4, and assuming that one half the work done on the beam goes Into heating the beam, then determine the temperature increase in the beam for each foot that Is moved.

19. Radiant energy from the sun arrives at the earth at the rate of about 1400 watts/m of surface perpendicular to the sun's rays. If a reflection 1 m is used to concentrate sunlight on a cup containing 0.1 kg of water initially at ZO'C, how long will it take for the water to reach lOO'C?

20. How much more heat must be added to 1 kg of ice at O'C to convert It to steam than it is required to raise the temperature of 1 kg of water from 0℃ to lOO^'C?

21. Six kg of ice at -10*C is added to 6 kg of water at 10**C. Find the resulting temperature.

22. How much ice at -lO'C is required to cool a mixture of of 0.1 kg of ethylalcohol and 0.1 kg of water from 20"C to 5°C?

23. A 5 kg iron bar is taken from a forge of a temperature of 1000*^0 and plunged into a pall containing 10 kg of water at eo^C. How much steam is produced?

24. By mistake 0.2 kg of water at 0*0 is poured into a vessel containing liquid notrogen at -196 C. How much nitrogen vapourizes?

25. How much steam at 250'*F is required to meet 5 lb of ice at 32"F?

26. Ten lb of steam at 220^ is passed through 10 lb of water at 200'F. What is the temperature and physical state of the mixture afterward?

SPECIFIC OBJECTIVES

Topic #2

The student will be able to:

Structural Matter

1. Differentiate between: a) homogeneous and heterogeneous
   b) elements, compounds and solutions

2. State and give an example of the Law of Definite Proportions,

Thermal Expansion

3. State the formula relating change in length of a solid as a function of original length, change in temperature and the coefficient of linear expansion.

4. State the relationship between the coefficient of linear expansion and the coefficient of volumetric expansion.

5. State the formula relating change in volume of a solid as a function of original volume, change in temperature and the coefficient of volumetric expansion.

6. From the definitions of Young's modulus, stress and strain, determine the equation of deformation.

7. State Young's modulus for steel in both systems of units.

Gas Laws

8. Explain Charles Law according to the Kinetic Theory of Gases.

9. State in formula form: a) Charles Law b) Boyle's Law c) The Ideal Gas Law.

10. Explain why the Ideal Gas Law is so named.

11. Define the following: a) Pressure b) Absolute Pressure c) Absolute Temperature.

12. State the common units of pressure, temperature and volume in both Imperial and S.I. systems.

13. Convert from:
    a) Fahrenheit to Celsius degrees
    b) Celsius to Fahrenheit degrees
    c) Celsius to Kelvin degrees
    d) Kelvin to Celsius degrees
    e) Fahrenheit to Rankine degrees
    f) Rankine to Fahrenheit degrees

14. State in formula form, the average molecular kinetic energy of a gas.

15. State Boltzmann's constant.

16. Explain the process of evapouration by referring to the Molecular Motion in Liquid.

17. Answer completely and correctly the following questions and problems:

Unit #2 Thermal Properties of Matter

IMPORTANT FORMULAE

Thermal Expansion

^L = aLo^T
^V = bVoAT

Molecular Kinetic Energy

KE average = 3 KT
7

GAS LAWS

BOYLE'S LAW

pV = k (T is a constant)

CHARLES LAW

V = k (p is a constant)
T

IDEAL GAS

£V = K
T

Part I

Multiple Choice

1. **Two elements cannot be combined chemically to make:**
   a) a compound
   b) a gas
   c) another element
   d) a liquid

2. The relative proportions of the elements in a compound:
   a) may vary considerably
   b) may vary only slightly
   c) do not vary
   d) may or may not vary depending on the compound

3. A pinch of salt is added to a glass of water. The result is:
   a) an element
   b) a compound
   c) a solution
   d) a heterogeneous substance

4. Which of the following statements is incorrect:
   a) Matter is composed of tiny particles called molecules-
   b) These molecules are in constant motion.
   c) All molecules have the same size and mass.
   d) The differences between the solid, liquid and gaseous states can be attributed to the relative freedom of motion of their respective molecules*

5. The smallest subdivision of a compund that exhibits its characteristic properties is called:
   a) an elemental particle
   b) a molecule
   c) an element

6. The energy molecular motion appears in the form of:
   a) friction
   b) internal energy
   c) temperature
   d) potential energy

7. The volume of a gas sample is directly proportional to its:
   a) Fahrenheit temperature
   b) Celsius temperature
   c) absolute temperature
   d) pressure

8. Absolute zero may be regarded as that temperature at which:
   a) water freezes
   b) all gases become liquids
   c) all substances are solid

9. The Kinetic molecular theory of gases predicts that at a given temperature:
   a) all the molecules in a gas have the same average speed.
   b) all the molecules in a gas have the same average energy
   c) light gas molecules have lower average energies than heavy gas molecules
   d) light gas molecules have higher average energies than heavy gas molecules.

10. The volume of a gas is held constant while its temperature is raised. The pressure the gas exerts on the walls of its container is increased because:
    a) the mass of the particle increases
    b) each molecule loses more Kinetic energy when it strikes the wall
    c) the molecules are in contact with the wall for a shorter time
    d) the molecules have higher average speeds and strike the wall more often

11. The temperature of a gas is held constant while its volume is reduced. The pressure exerted by the gas on the walls of its container increases because its molecules:
    a) strike the container walls more often
    b) strike the container walls with higher velocities
    d) strike the container walls with greater force
    d) have more energy

12. In the formula kE = 2 l^T, k is known as:
    2
    a) the atomic mass constant
    b) Boyle*s constant
    c) George's variable constant of equalization
    d) Boltzman*s constant

13. A copper bar is Im long at 20**C- At what temperature will it be shorter by 1mm?

14. An absolute temperature of lOO^K is the same as a Celsius temperature of:
    a) -173"C
    b) 32"C
    c) 212*0
    d) 373**C

15. The boiling point of water on the Rankine scale is:
    a) .248*R
    b) -erR
    c) 485'R
    d) 672''R

16. A container holds 1 kg of air at atmospheric pressure. If another Kilogram of air is pumped into the container, the pressure is:
    a) *h* atm
    b) 1 atm
    c) 2 atm
    d) 4 atm
17. If the absolute pressure on 10 ft-^ of air is increased from 32 Ib/in^ to 120 Ib/in^, the new volume of the air will be:
    a) 2.5 ft^
    b) 5 ft^,
    c) 40 ft^^
    d) 900 ft^
18. A sample of hydrogen gas is compressed to half its original volume while its temperature is held constant. If the average velocity of the hydrogen molecules was originally "V", then the new average velocity is:
    a) 4V
    b) 2V
    c) V
    d) V
    7
19. At which of the following tempreatures would the molecules of a gas have twice the Kinetic energy they have at 20°C?
    a) 40°C
    b) 80'C
    c) 313*C
    d) 580°K
20. The mass of a nitrogen molecule is seven times greater than that of a hydrogen molecule. The temperature of a sample of hydrogen whose average molecular weight is equal to that of a sample of nitrogen at 300'K is:
    a) 66"K
    b) 43"K
    c) 300*K
    d) 2100**K

EXERCISE

1. Classify the following substances as homogeneous or heterogeneous: sale, leather, stone, diamond, iron, blood, solid Carbon Monoxide, gaseous Carbon Monoxide, Helium, and rust.

2. Classify the following homogeneous liquids as elements, compounds, or solutions:
   mercury, alcohol, gin, pure water, sea water, bromine, tea, glycerin, liquid oxygen, liquid air

3. In the consturction of a light bulb, wires are led through the glass at the base by means of air-tight seals. If the wires were made of copper, what would be expected to the bulb and its components when the bulb heats up? What does this imply about the lead-in wires, successfully used for this purpose?

4. Starting with the "Ideal Gas Law" obtain an equation relating the pressure and temperature of a gas at constant volume.

5. Verfiy that the force associated with the thermal expansion or contraction of a solid object depends upon its cross sectional area, but not upon its length.

6. At absolute zero, an Ideal 6As would occupy zero volume. Why would an actual gas not do so?

7. According to the Kinetic theory of gases, molecular motion ceases only at absolute zero. How can this be reconciled with the definite shape and volume of a solid at temperatures well above absolute zero?

8. Molecular speeds compare favorably with those of rifle bullets. Yet a gas with a strong odour (such as that produced by combination in a digestive system using eggs and beer) takes a few minutes to diffuse through a room. Why?

9. Actual molecules attract one another slightly. Does this tend to increase or decrease gas pressures from valves computed from the Ideal Gas Law? Why?

10. A steel bridge Is 300 ft- long at 80*'F. What is its change in length when the temperature drops to 20'*F?

11. A steel tape measure is calibrated at 70**F. A reading of 120'0" is obtained when it is used to determine the width of a building at 0'*F. What is the true width of the building at 0°F?

12. Now large a gap should be left between steel rails that are 10 m long, when laid at 20'C if they are just able to touch at 30'C?

13. A rod 2 m long expands by 1 mm when heated from 8°C to 70"C. Determine the coefficient of linear expansion of the rod material.

14. The outside diameter of a wheel is 1.000 m. An iron tire for this wheel has an inside diameter of 0.992 m at 20^*0. To what temperature must the tire be heated in order to be the same diameter as the wheel?

15. A pyrex beaker is filled to the brim with 250 ml^ of glycerin at 15°C. How much glycerin overflows at 25°C?

16. A pyrex container holds 500 ml^ of mercury at 0°C. How much mercury win run out when it is heated to 80*0?

17. Vodka, at 100 proof is half ethyl alcohol and half water. How much profit per litre will a boot-legger make If he buys at $5.00 per litre at SO'F and sells at $5.00 per litre at 80**F?

18. A concrete swimming pool, 40* x 20' x 8', Is filled with water to within V of the top when the temperature is 50°F. Using a coefficient of linear expansion for concrete as 0.5 x lO^S/'F, determine what temperature would cause the water to begin to overflow?

19. A sample of gas occupies 2 m^ at 300*K and an absolute pressure of 2 x 10^ N

    a) What is the pressure at the same temperature when it has been compressed to 1 m^?

    b) What is its volume at 300'*K when its pressure has been decreased to 1.5 X 10^ N
    m2

    c) What is the volume at a temperature of 400'K and a pressure of 2 X 10^]j

20. A sample of gas occupies 100 ml at 0"C and 1 atm. pressure. What is Its volume:

    a) at SO^C and 1 atm?

    b) at 0^*0 and 2.2 atm?

    c) at SO^C and 2.2 atm pressure?

21. A sample of gas occupies a volume of 8 ft^ at a temperature of 400 R and 1 atm. What is the volume at 500 R and 1 atm?

22. An automobile tire contains air at a gauge pressure of 24 Ib/in^ at 40'F. If the volume of the tire remains the same, what will the pressure be when the temperature becomes 80**F?

23. To what temperature must a gas sample initially at 27*"C be raised to
    a) double the average energy of its molecules?
    b) double the average speed of the molecules?

PROBLEMS

1. An aluminum mast whose cross sectional area is 0.05 ft^ is 60 ft long at 60°F.
   a) By how much does it increase in length when its temperature rises to lOO'F?
   b) How much force is associated with the expansion?

2. The mast in problem 1 is held in place by 4 steel guys that run from the top of the mast to anchors in the ground 10 ft. from the base of the mast. The guy wires are 0.25 inches in diameter and each has a breaking strength of 6000 Ibf. If the wires are initially under a tension of 1000 Ibff each at eo^F, at what temperature will the difference in expansions of the mast and wire cause the wire to break?

3. A load of 4000 kg is placed on a vertical steel column 3 m long and having a cross sectional area of 50 cm^ when the temperature is 20**C. To what temperature should the steel column be raised if the length of the column is to be the same after the load is applied as it was originally?

4. A diver blows an air bubble 1 cm in diameter at a depth of 10 m in a fresh water lake, where the temperature is 5°C. What is the diameter of the bubble when it reaches the surface of the lake where the temperature is 20^0? Assume that the air in the bubble is always at the temperature of the surrounding water.

   Note V = r^ sphere

5. A large balloon whose volume is 20,000 *fU^* is to be filled with helium at atmospheric pressure. The helium is stored in cylinders of volume 2 fit-^ at a pressure of 300 Ib/in^ gauge. How many cylinders are required?

6. A tank containing 0,1 m^^ of nitrogen at room temperature and at 8 x 106 N/m^ is connected through a valve to an empty tank of volume 0.4 m3.
The valve is opened and the nitrogen is allowed to expand. After the system returns to room temperature, what is the pressure in the tank?

7. A sealed tank contains air at 10**C. A gauge reads 24 Ib/in^, what will the gauge read if the temperature rises to SO'^C?

8. A vertical cylindrical tank is 42 cm tall and 2.00 cm in radius and is open at the top. Atmospheric pressure is 101.3 KPa. A close fitting cylindrical plug of mass 5.00 kg is inserted at the top and falls inside- If the temperature of the trapped air does not change, how far from the top of the cylinder is the base of the plug when it comes to rest?

9. On a day when atmospheric pressure is 15 Ib/in^, a cylindrical diving bell 8 ft. tall is lowered to the bottom of a river. It is observed that water rises inside the bell to within 3 feet of the top.

   a) What is the pressure of the air in the diving bell?
   b) How deep is the river. (Assume constant temperature)

PHYSICS OF HEAT

TABLES OF LINEAR & VOLUME EXPANSION

Coefficients of Linear Expansion

Substance	Coefficient	Coefficient
	x 10 rz	X10 r?
Aluminum	2.4	1.3
Brass	1.8	1.0
Concrete	0.7-1.2	0.4-0.7
Copper	1.7	0.94
Iron	1.2	0.67
Lead	3.0	1.7
Quartz	0.05	0.008
Silver	2.0	1.1
Steel	1.2	0.67

Coefficients of Volume Expansion

Substance	Coefficient	Coefficient
	X10 rz	X10 rv
Ethyl alcohol	1.1	6.1
Glass (average)	0.2	0.1
Glycerin	5.1	2.8
Ice	0.5	0.3
Mercury	1.8	1.0
Pyrex glass	0.09	0.05
Water	2.1	1.2
Water	2.1	1.2

SPECIFIC OBJECTIVES

TOPIC #3

The student will be able to:

Laws of Thermodynamics

1. State the three characteristic processes that take place in all heat engines.
2. State the first Law of Thermodynamics.
3. State the second Law of Thermodynamics.
4. Recall the meanings of Heat, Work and Internal Energy.
5. Recall the formalae for Potential Energy and Kinetic Energy.
6. State the units of energy and power in both Imperial and S.I. systems.
7- Define the term Isothermal Process.
8. Define the term Adiabatic Process.

Carnot Engine

9. Define efficiency.
10. Define Carnot efficiency.

Real Engines

11. With the aid of a schematic diagram, explain the operation of a steam engine.
12. Explain the operation and function of a condenser,
13. Define "Heat of Combustion".
14. State the units of Heat of Combustion in both Imperial and S.I. systems.
15. Using P-V diagrams, describe the operation of the following, making particular reference to processes with the cycle.
    a) Reciprocating gasoline engine
    b) Diesel engine
    c) Gas turbine
16. Correctly complete the following questions and problems of this topic.

Introduction to Thermodynamics

Multiple Choice

1. A heat engine operates by taking in heat at a particular temperature and:
   a) converting it all into work
   b) converting some of it into work and exhausting the rest at a lower temperature
   c) converting some of it into work and exhausting the rest at the same temperature
   d) converting some of it into work and exhausting the rest at a higher temperature

2. The first law of thermodynamics is the same as the:
   a) second law of thermodynamics
   b) law of conservation of energy
   c) law of conservation of momentum
   d) first law of motion

3. The natural direction of heat flow is from a high-temperature reservoir to a low-temperature reservoir, regardless of their respective heat contents.

   The fact is incorporated in the:
   a) first law of thermodynamics
   b) second law of thermodynamics
   c) law of conservation of energy
   d) principle of superposition

4. _ The work output of every heat engine:
   a) equals the difference between its heat intake and heat exhaust
   b) equal that of a Carnot engine with the same intake and exhaust temperatures
   c) depends only upon its intake temperature
   d) depends only upon it exhaust temperature

5. Which of the following engines is normally the least efficient?
   a) reciprocating steam engine
   b) diesel engine
   c) gas turbine
   d) Carnot engine

6. Which of the following engines is the most efficient?
   a) reciprocatfng steam engine
   b) diesel engine
   c) gas turbine
   d) Carnot engine
7. A Carnot engine turns heat into work:
   a) with 100% efficiency
   b) with *0%* efficiency
   c) without itself undergoing a permanent change
   d) with the help of expanding steam
8. In any process, the maximum amount of heat that can be converted to mechanical energy:
   a) depends on the amount of friction present
   b) depends on the intake and exhaust temperatures
   c) depends on whether kinetic or potential energy is involved
   d) is 100%
9. In any process, the maximum amount of mechanical energy that can be converted to heat:
   a) depends on the amount of friction present
   b) depends on the intake and exhaust temperatures
   c) depends on whether kinetic or potential energy is involved
   d) is 100%
10. An adiabatic process in a system is one in which:
   a) no heat enters or leaves the system
   b) the system does not work nor is work done on it
   c) the temperature of the system remains constant
   d) the pressure of the system remains constant

11- A frictionless heat engine can be 100% efficient only if its exhaust temperature is:
   a) equal to its input temperature
   b) less than its input temperature
   c) 0**C
   d) 0 K

12- When a gas is in equilibrium, its molecules:
   a) all have the same energy
   b) have different energies which remain constant
   c) have a certain constant average energy
   d) do not collide with one another

13. A system of molecules whose energies are distributed in the most probable way:
    a) can perform an amount of mechanical work equal to its total energy content
    b) can perform an amount of mechanical work that depends on Its absolute temperature
    c) cannot perform any mechanical work
    d) Is a Carnot engine

14. An Ideal engine absorbs heat at a temperature of 127*C and exhausts heat at a temperature of 77*C. Its efficiency is:
    a) *U%*
    b) 39%
    c) 61%
    d) 88%

15. If a heat engine exhausting heat at 140*F is to have an efficiency of 33%, it must take in heat at:
    a) 200"F
    b) 440'*F
    c) 660'F
    d) QOO'^F

EXERCISES

1. Two Identical watches, one wound and the other unwound, are dropped into beakers of acid and completely dissolved. Is there any difference between the two reactions? Justify your answer using physical principles.

2. The sun's corona Is a very dilute gas at a temperature of about lO'^K that is believed to extend Into interplanetary space at least as far as the earth's orbit. Why can we not use the corona as the high temperature reservoir of a heat engine In an earth satellite?

3. A gas sample expands from V^ to V2. Does it perform the most work when the expansion takes place at constant pressure, at constant temperature, or adiabatically? In which process does the gas perform the least work?

4. The operation of a steam engine proceeds approxiamtely as follows: (1) water Is heated to the boiling point; (2) the water turns into steam and expands at constant pressure at its boiling point; (3) the steam enters the cylinder of the engine and expands adiabatically against the piston; (4) the spent steam condenses Into the water and is returned to the boiler. Plot the entire cycle on a p-V-diagram and indicate In what parts of the cycle heat is absorbed, heat is rejected, and work is done on the outside world.

5. There are fours parts to each cycle of a gasoline engine: (1) a gasoline-air mixture enters the cylinder from the carburetor and is compressed adiabatically by the piston; (2) the mixture is detonated by the spark plug at the instant of maximum compression, and the pressure rises sharply before the piston begins to move outward; (3) as the piston moves out, the burnt gases expand adiabatically; and (4) the gases leave the cylinder through the exhaust valves when the piston is at the bottom of its stroke, so this is essentially a constant-volume process. Plot the entire cycle on a p-V-diagram and indicate in what parts of the cycle heat is absorbed, heat is rejected, and work is done on the outside world.

6. What Is the maximum possible efficiency of an engine that obtains heat at 400"F and exhausts heat at IBO'^F?

7. An engine operating between 580**F and 120°F is 15% efficient. What would its efficiency be if it were a Carnot engine?

8. A Carnot engine takes in 4185 kJ of heat from a reservoir at 327""C and exhausts heat to a reservoir at 127*C. How much work does it do?

9. One of the most efficient engines ever developed operates between about 2000 K and 700 K. Its actual efficiency is 40%. What percentage of its maximum possible efficiency is this?

10. An engine is proposed which is to operate between 400**F and lOO^F with an efficiency of 40%. Will the engine perform as indicated? If not, what would its maximum efficiency be?

11. A Carnot engine absorbs 840 kJ of heat at 500 K and exhausts 630 kJ. What is the exhaust temperature?

12. How many cubic feet of propane must be burned to heat 12 gallons of water from 50'F to 212**F? Assume that 20% of the heat is wasted. (One gallon of water weighs 8.3 lb)

13. How many cubic meters of coal gas must be burned to heat 500 liters of water from 5°C to 90'*C? Assume that 25% of the heat is wasted. (The mass of 1 liter of water is 1 kg)

14. In a certain power station coal is consumed at the rate of 1 Ib/hr for each kilowatt of electrical output. Find the overall efficiency of the power station.

15. A 4250-hp aircraft engine is used in a power station in England to run a 3 megawatt generator to supply electricity during peak-load periods. The engine consumes 0.82 lb of kerosene per kilowatt-hour of energy produced. What is the overall efficiency of the installation?

PROBLEMS

1. A Carnot engine whose efficiency is 35% takes in heat at lOOO'F. What must the intake temperature be if the efficiency is to be 50% with the same exhaust temperature?

2. Three designs for a heat engine to operate between 450''K and SOO'K are proposed. Design A is claimed to require a heat input of 0.2 kcal for each 1000 J of work output, design B a heat input of 0.6 kcal, and design C a heat input of 0.8 kcal. Which design would you choose and why?

3. The total drop of the Wollomombi Falls in Australia is 1580 ft. What would be the Carnot efficiency of an engine operating between the top and bottom of the falls if the water temperature at the top were 50"F and all the potential energy of the water at the top were converted to heat at the bottom?

4. A certain 70-kg man requires energy at the rate of 70 W when he is resting (this is his "basal m etabolism"). When he is walking up a 10'-hill at 2 m/s, his power requirements increases to 300 W, so that the net power input attributable to his motion is 230 W. What is the efficiency with which he converts food energy into gravitational potential energy?

5. Starting from the definition of work, show that the amount of work done by a gas that expands by ^V at the constant pressure p is W = pAv.

6. Use the result of the previous problem to find the percentage of the heat of vaporization of water that represents the work involved in expanding water into steam against the pressure of the atmosphere. At 212*F and atmospheric pressure a cubic foot of water weighs 60 lb and a cubic foot of steam weighs 0.0375 lb.

7. A certain jet airplane uses 40 metric tons {1 metric ton = lO^kg) of fuel for a flight lasting 8 hours, (a) If the fuel is kerosene, how much energy in kcal is liberated during the flight? (b) How much energy in J?, (c) If the engines of the airplane develop an average of 30,000 hp during the flight, what is their percentage efficiency?

8. A certain jet airplane uses 20,000 lb of fuel in travelling 900 mi- at an average velocity of 500 mi/hr. (a) If the fuel is kerosene, how much energy in Btu is liberated during the flight? (b) How much energy in ft-lb? (c) If the engines of the airplane develop an average of 15,000 hp during the flight, what Is their percentage efficiency?

9. A certain Diesel engine consumes 4 gallons of fuel per hour when It is developing 58 hp. Find its efficiency. (Diesel oil weighs 6.7 lb per gallon.)

10. At 800 rpm a Diesel engine develops 80 hp and consumes 40 lb of fuel per hour. At 1800 rpm the same engine develops 160 hp and consumes 70 lb of fuel per hour. Find its efficiency at each speed.

11. A 2000-hp coal-burning steam locomotive has an overall efficiency of 10%. How many tons of coal does it consume per hour?

12. A certain power station consumes 20,000 tons of coal per day. The overall efficiency of the station is 40%. Find the number of kilowatts of electricity the station produces.

SUBSTANCE	HEAT OF COMBUSTION	
Solids	Btu/lb	kJ/kg
Charcoal	14,600	33,890
Coal	14,000	32,600
Wood	8,000	18,800
Liquids	Btu/lb	kJ/kg
Gas	20,400	47,300
Diesel Oil	19,400	44,800
Domestic Fuel Oil	19,500	45,200
Ethyl Alcohol	14,000	32,600
Kerosene	19,800	46,000
Gases	Btu/ft	kO/m
Hydrogen	275	10,230
Acetylene	1,450	53,970
Propane	2,330	86,200
Natural Gas	900 2.000	33,500 - 71,000
Coal Gas	490	18,000

Volumes at 0*C and atmospheric pressure.

Specific Objectives

Topic H

The student will be able to:

1. Describe the mechanisms involved in the conduction form of heat transfer.
2. Describe the mechanisms involved in the radiation form of heat transfer.
3. Describe the mechanisms involved in the convection form of heat transfer.

Conduction

4. State the formula for heat transfer due to conduction.
5. State the units of the thermal conductivity in both Imperial and S.I. units.
6. Provided with the formula, calculate the amount of heat flow due to conduction through:
   a) A thin cylinder
   b) A thick cylinder
   c) A composite thick cylinder

The Refrigerator

7. By comparison to a heat engine, describe the operation of a refrigerator.
8. Provided with the diagram of a refrigerator system, describe the changes in the working fluid as the system is traced.
9. State the formula for the coefficient of performance of a Carnot refrigerator in terms of temperature.
10. State the formula for any refrigerator in terms of absorbed heat and work required.
11. Define the refrigeration ton in both S.I. and Imperial units.
12. Correctly complete the following questions and problems of this topic

HEAT TRANSFER

Heat can be transferred from one place to another by means of conduction, convection or radiation* In conduction heat Is transported by successive molecular collisions, and in convection by the motion of a volume of hot fluid from one place to another. The thermal conductivity of a material is a measure of its ability to conduct heat.

Heat transfer by radiation takes place by means of electromagnetic waves which require no material medium for their passage.

A refrigerator is a device that transfers heat from a cold reservoir to a hot one, and it must expend energy in order to do this. In essence, it is a heat engine operating in reverse.

The coefficient of performance of a refrigerator is the amount of heat removed per unit of work done.

The capacity of a refrigerator is the rate at which it can remove heat. The conventional unit of refrigeration capacity is the ton which is that rate of heat removal which can freeze 1 ton of water at its freezing point to ice at the same temperature per day; one refrigeration ton is equal to 12,000 Btu/hr.

Important Formulas:

Heat conduction : $$Q = \frac{kAtAT}{3}$$

Refrigeration coefficient of performance:

C.P-^ *Qi*_ _ Qj___

(ideal refrigerator)

^ -'

Multiple Choice

1. The natural direction of the heat flow between two reservoirs depends on:
   a) their temperatures
   b) their internal energy contents
   c) their pressures
   d) whether they are in the solid, liquid, or gaseous state
2. Metals are good conductors of heat because:
   a) they contain free electrons
   b) their atoms are relatively far apart
   c) their atoms collide infrequently
   d) they have reflecting surfaces
3. The rate at which heat flows through a slab of some material does not depend on:
   a) the temperature difference between the faces of the slab
   b) the thickness of the slab
   c) the area of the slab
   d) the specific heat of the material
4. The materials with the highest conductivities are the:
   a) gases
   b) liquids
   c) woods
   d) metals
5. In natural convection, a heated portion of a fluid moves because:
   a) its molecular motions become aligned
   b) of molecular collisions within it
   c) its density is less than that of the surrounding fluid
   d) of currents in the surrounding fluid
6. Newton's law of cooling applies to heat loss by:
   a) conduction
   b) convection
   c) radiation
   d) refrigeration
7. Four pieces of iron are heated in a furnace to different temperatures. The one at the highest temperature appears:
   a) white
   b) yellow
   c) orange
   d) red

8. Electromagnetic radiation is emitted:
   a) only by radio and television antennas
   b) only by bodies at higher temperatures than their surroundings
   c) only by bodies at lower temperatures than their surroundings
   d) by all bodies

9. The physics underlying the operation of a refrigerator most closely resembles the physics underlying:
   a) a heat engine
   b) the melting of ice
   c) the freezing of water
   d) the evaporation of water

10. A refrigerator:
   a) produces cold
   b) causes heat to vanish
   c) removes heat from a region and transports it elsewhere
   d) changes heat to cold

11. The working substance {called the refrigerant) of most refrigerators is:

   a) a liquid with a very low vaporization temperature
   b) a liquid with a very high vaporization temperature
   c) a gas that is readily liquified
   d) a liquid that is readily solidified

12. Of the following, the one that is not a type of refrigerant is:

   a) Freon
   b) superheat
   c) ammonia
   d) sulfur dioxide

13. A refrigerator exhausts:

   a) less heat than it absorbs from its contents
   b) the same amount of heat it absorbs from its contents
   c) more heat than it absorbs from its contents
   d) any of the above, depending on the circumstances

14. A refrigeration ton is the rate of heat removal that can:
   a) cool 1 ton of water by 1*F per hour
   b) cool 1 ton of water by l^F per day
   c) freeze 1 ton of water at 32^F per hour
   d) freeze 1 ton of water at 32**F per day

15. Between which of the following pairs of temperatures would an ideal refrigerator have the highest coefficient of performance?
    a) -20*0 and -10*C
    b) -20'C and lO'^C
    c) lO'C and 20*0
    d) 20'*C and 30*C

Exercises

1. What condition is necessary for heat to flow through an object?

2. In the winter, why does the steel blade of a shovel seem colder than its wooden handle?

3. A thermos bottle consists of two glass vessels, one inside the other, with the space between them evacuated. The vessels are both coated with thin films of silver. Why is this device so effective in keeping the contents of the bottle at a constant temperature?

4. By what mechanism or mechanisms does a man seated in front of a fire receive heat from it? A man seated in front of a radiator through which hot water is circulated?

5. Under what circumstances does an object radiate electromagnetic waves? How is the predominant wavelength in the radiation related to the temperature of the object?

6. In an attempt to cool a room in the summer, a man turns on an electric fan and leaves the room. Will the room be cooler when he returns?

7* An attempt is made to cool a kitchen during the summertime by leaving the refrigerator door open and closing kitchen door and windows. What will happen and why?

8. An oak door 3 in. thick is to be removed and the opening bricked up. How thick should the brick wall be if the rate of heat transfer through this part of the building is to be unchanged?

PROBLEMS

1. The layer of ice on a frozen lake is 2 in. thicR at 5 p.m. During the night the air temperature is 28'F and the temperature of the water beneath the ice is 32*F. Now thick is the ice at 8 a.m. the next morning?

2. An igloo of compacted snow has a surface area of 24 m^ and a wall . thickness of 40 cm. The thermal conductivity of the snow is 2 x 10 kcal/m. sec.'C. If the temperature inside the igloo is 20*C and the outside temperature is -lO^C, how much blubber (heat of compubstion = 9500 kcal/kg) must be burned per hour to keep the interior temperature constant? Neglect the melting of the igloo wall and the heat evolved by the igloo's inhabitants.

3. Three designs for a refrigerator to operate between -20°C and 40**C are proposed. Design A is claimed to require 300 J of work for each kcal of heat extracted, design B to require 950 J, and design C to require 2000 J. Which design would you choose and why?

4. A Carnot refrigerator is used to make 1 kg of ice at -10°C from 1 kg of water at 20°C, which is also the temperature of the kitchen. How many joules of work must be done?

5. In its operation, a refrigerator absorbs heat from a storage chamber at -23**C and exhausts heat at 27'*C. The rate at which heat is exhausted is found to be 60 kcal/min, and the coefficient of performance is half - that of a Carnot refrigerator.

   a) Now much heat is absorbed from the storage chamber per minute?
   b) How much power does the refrigerator require?

6. A 3/4 ton window air conditioner is found able to maintain a constant temperature of 70*'F in an empty room when the outside temperature is 90**F by running half the time. A sitting person liberate about 400 Btu/hr, How many people can sit reading in the room, each with his own 75-watt lamp, without exceeding the capacity of the air conditioner?

7. An ice-making plant produces 50 tons of ice per day at IS^F from water at 60**F. Assuming no losses, what must be the refrigeration capacity of the plant?

8. Ice cream has a specific heat of 0.78 Btu/lb*F afterward. Its heat of fusion is 126 Btu/lb, and it freezes at 28°F. What refrigeration capacity is required to produce 60 lb of Ice cream at 8°F from a mix at 6 0 T in 1 hour?

9. What thickness of (a) concrete, (b) brick, and (c) pine wood have the same Insulating ability as 4 in. of glass wool?

10. The steel hull of a boat 1s 6 mm thick and its underwater area is IZO^m . If the water temperature is 26'C and the temperature of the boat*s interior is 20'C, how much heat per day enters the boat through the hull?

11. An insulated copper rod 5 mm on a side of 1 m long has one end in a steam bath and the other in contact with a block of Ice at O'C. How much ice melts per hour?

12. The walls of a certain domestic refrigerator are equivalent to a 60 ft.2 slab of cork 3 in. thick. If the interior of the refrigerator is at an average of 40°F and the kitchen temperature is 70*F, what Is the rate of heat flow through the refrigerator walls?

13. A double boiler has an aluminum upper pan whose bottom is 20 cm in diameter and 0.9 mm thick. If the lower pan contains boiling water and the upper one milk at 5*0, compute the rate of heat transfer to the milk. What happens to this rate as the milk warms up?

14. A glass of beer warms from 45**F to 50**F in 3 min. when the air temperature Is 95**F. How long will it take to warm from 55'*F to 60°F?

15. A roast turkey cools from 150*F to HO^F in 5 min. when it Is in a room whose temperature is 70'F. How long will It take to cool from 110*F to 100**F in the same room?

16. A Carnot refrigerator extracts heat from a freezer at -5*'C and exhausts it at 25'C. How much work per keal of heat extracted is required?

17. A Carnot refrigerator exhausts heat at 27**C. If half as much mechanical energy must be provided as the amount of heat extracted, find the temperature at which the heat Is extracted.

18. A Carnot refrigerator extracts heat at 0*F and exhausts it at 120°F. How much work per Btu of heat extracted is required?

19. A certain refrigerator that absorbs heat at S^F and exhausts it at 85"F has a coefficient of performance of 3,0. What would the coefficient of performance of a Carnot refrigerator be that operated between the same two temperatures?

20. A 5 ton air conditioner is 40% efficient. How many horse-power are needed to operate its compressor?

21. An aperture 8 ft. long and 5 ft. high is cut in the west wall of ahous and a picture window is installed. The window consists of two panes of glass separated by an air space, and its thermal conductivity is the same as that of the wall material it replaces. In the afternoon an average of 150 Btu/hr of solar radiation passes through each ft^ of window area. What is the additional load (in refrigeration tons) on the house's air conditioning system?

•

%

Thermal conductivities in the vicinity of room temperature (20*C or 68*F)

Material	k, Btu ft. 2 fr.T/in	k. kJ m.s.'C
Metals		
Silver	2.9 X: 103	41.2 X 10-2
Copper	2.7 X; 103	38.5 X 10-2
Alumlnum	1.5 >; 10^	21.3 X 10-2
Brass	0.73 X 103	1.0 X 10-2
Iron & Steel	0.32 X 103	0.46 X 10-2
Other Solids		
Ice	15	21.8 X 10-4
Concrete	12	17.2 X 10-4
Glass	5.5	7.9 X 10-4
Brick	5.0	7.1 X 10-4
Oak	1.1	1.6 X 10-4
Pine	0.8	1.2 X 10-4
Liquids		
Water	4.2	5.881 X 10-4
Insulating Materials		
Sawdust	0.41	0.59 X 10-4
Cork	0.3	0.42 X 10-4
Rock & Glass Wool	0.27	0.39 X 10-4
Kapok	0.24	0.35 X 10-4
Gases		
Hydrogen	1-2	1.72 X 10-4
Air	0.16	0.23 X 10-4