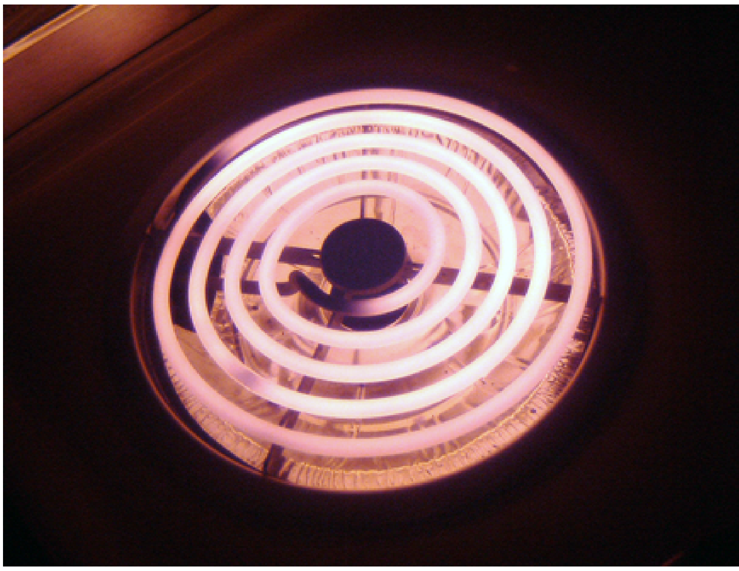
Physics Module 5

Thermal physics

Prepared by Dr. Tilahun Tesfaye



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NOTICE

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Foreword

This module has four major sections

The first one is the **INTRODUCTORY** section that consists of five parts vis:

Title: The title of the module is clearly described

Pre-Requisit Knowledge: In this section you are provided with information regarding the specific pre-requisite knowledge and skills you require to start the module. Carefully look into the requirements as this will help you to decide whether you require some revision work or not.

Time Required: It gives you the total time (in hours) you require to complete the module. All self tests, activities and evaluations are to be finished in this specified time.

Materials Required: Here you will find the list of materials you require to complete the module. Some of the materials are parts of the course package you will receive in a CD-Rom or access through the internet. Materials recommended to conduct some experiments may be obtained from your host institution (Partner institution of the AVU) or you may acquire borrow by some other means.

Module Rationale: In this section you will get the answer to questions like "Why should I study this module as pre-service teacher trainee? What is its relevance to my career?"

The second is the CONTENT section that consists of three parts:

Overview: The content of the module is briefly presented. In this section you will fined a video file (QuickTime, movie) where the author of this module is interviewed about this module. The paragraph overview of the module is followed by an outline of the content including the approximate time required to complete each section. A graphic organization of the whole content is presented next to the outline. All these three will assist you to picture how content is organized in the module.

General Objective(S): Clear informative, concise and understandable objectives are provided to give you what knowledge skills and attitudes you are expected to attain after studying the module.

Specific Learning Objectives (Instructional Objectives): Each of the specific objectives, stated in this section, are at the heart of a teaching learning activity. Units, elements and themes of the module are meant to achieve the specific objectives and any kind of assessment is based on the objectives intended to be achieved. You are urged to pay maximum attention to the specific objectives as they are vital to organize your effort in the study of the module.

The third section is the bulk of the module. It is the section where you will spend more time and is referred to as the **Teaching Learning Activities**. The gist of the nine components is listed below:

Pre-assessment: A set of questions, that will quantitatively evaluate your level of preparedness to the specific objectives of this module, are presented in this section. The pre-assessment questions help you to identify what you know and what you need to know, so that your level of concern will be raised and you can judge your level of mastery. Answer key is provided for the set of questions and some pedagogical comments are provided at the end.

Key Concepts: This section contains short, concise definitions of terms used in the module. It helps you with terms which you might not be familiar with in the module.

Compulsory Readings: A minimum of three compulsory reading materials are provided. It is mandatory to read the documents.

Compulsory Resources: A minimum of two video, audio with an abstract in text form is provided in this section.

Useful Links: A list of at least ten websites is provided in this section. It will help you to deal with the content in greater depth..

Teaching And Learning Activities: This is the heart of the module. You need to follow the learning guidance in this section. Various types of activities are provided. Go through each activity. At times you my not necessarily follow the order in which the activities are presented. It is very important to note:

- formative and summative evaluations are carried out thoroughly
- all compulsory readings and resources are done
- as many as possible useful links are visited
- feedback is given to the author and communication is done

Enjoy your work on this module.

I. Thermal Physics

By Dr. Tilahun Tesfaye, Addis Ababa University Ethiopia

Figure 1
Heat loss is a significant problem in these times of energy consciousness.

II. Prerequisite Course Or Knowledge

In order to study this module you need a good background of school physics at +2 level.

III. Time

This module can be completed in 120hrs.

IV. Materials

The following list identifies and describes the equipment necessary for all of the activities in this module. The quantities listed are required for each group.

1. **Immersion heater**- These are relatively inexpensive and readily available. Some have just the aluminum clad nichrome coils; others have an aluminum housing surrounding the coils. Considering their low cost and repeated use in four of this module's activities it would be very wise to have one and back-up units.
2. **Balance**- A beam or spring balance with a capacity of 500g and a sensitivity of ± 0.1 g will be good enough. Some centigram balances have a capacity of 300g
3. **Styrofoam cups** (2)- Get the 14 or 16 oz. size. These cups will be used greatly, so it would be wise to have extra cups on hand.
4. **Thermometer** (1)- A regular -20 to110° C lab thermometer will suffice as long as students are cautioned that the bulb is fragile.
5. **Large container for water:**

6. **Iron washers (6)**
7. **Crushed ice**
8. **250 mL beaker**

Figure 2
Thermometers use a change in physical properties to measure temperature.

V. Module Rationale

Physics is a study of Energy and its transformations. Heat is the most common form of energy that is transferred or transformed when bodies interact. This module will help you understand the concept of heat as a form of energy and the mechanisms related to its conversion and transformation.

Conversion and transformation of heat has an effect of altering the temperature of the interacting systems. Temperature variation in turn has effects on our personal comfort and on substances that we use every day. The methods presented in this module have applications in almost all areas of professions. Daily temperature in weather forecast, medical professionals, craftsmen, technicians etc. monitor temperature for various purposes in various methods. You will develop skills of measuring temperature and using them to analyze the laws of heat exchange and broader science of thermodynamic laws.

Therefore inclusion of a module on thermal physics is justified by the above mentioned facts.

Figure 3
Fire wood is widely used for cooking in rural areas of Africa

VI. Content

6.1 Overview

The central concepts of this module (Thermal Physics) are heat and temperature. The module begins with the study of temperature and its units of measurement.

Activities related to the second unit will guide you to distinguish between heat and temperature; to study the concept of heat, the mechanisms of heat flow, the amount of heat required to raise the temperature of a given object, and the relation between heat and work (Energy).

The concepts of temperature and heat will be utilized in the study of gases and the kinetic theory of gasses. The activities at the end of the module will further consolidate theories.

The study of heat engines is included as an application to supplement comprehension of theories on heat and temperature.

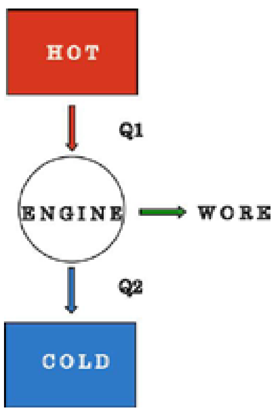


Figure 4
Heat engine makes use of heat to do work

6.2 Outline

Unit 1 Introduction **10hrs**

Temperature
Zeroth law of thermodynamics
Temperature Scales

Unit 2 Heat **30hrs**

Specific Heat Capacity
Heat and Work
First Law of Thermodynamics
Transfer of heat
Conduction, Convection and Radiation

Unit 3 Gases **25hrs**

Avogadro's number
Ideal and Real Gases
P-V diagrams

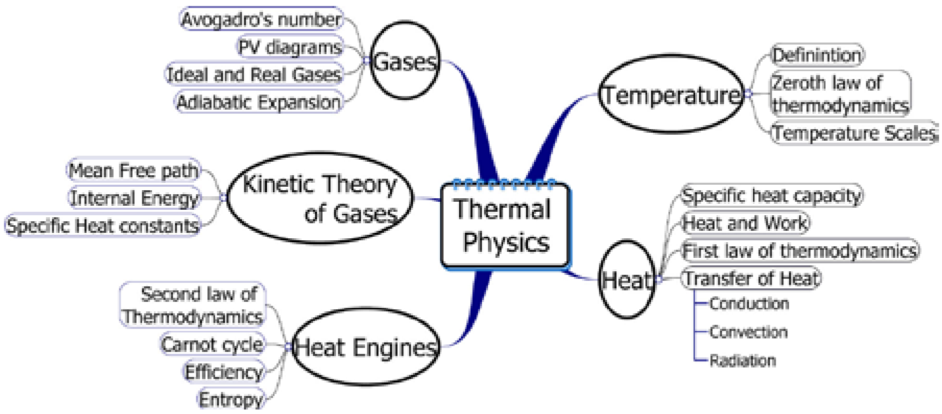
Unit 4 Kinetic Theory of Gases **23hrs**

Mean free path
Internal Energy
Specific heat Constants

Unit 5 Heat Engines **32hrs**

Second Law of Thermodynamics
Carnot Cycle
Efficiency
Entropy
Conduction, Convection and Radiation

6.3 Graphic Organizer



VII. General Objective(S)

After completing this module you will be able to

- Appreciate that thermal physics involves the study of heat as a form of energy transfer and the application of energy conservation
- Understand the concept of temperature, heat and internal energy
- Understand the underlying basis of thermodynamics first law
- Understand the properties of gases and use P-V-T diagrams
- Understand kinetic theory of gases
- Understand the second law of thermodynamics and entropy

VIII. Specific Learning Objectives (Instructional Objectives)

Content	Learning objectives After Completing this section you would be able to:
Temperature (10 hours) • Temperature. • Zeroth Law of Thermodynamics. • Temperature scales.	• Define temperature • Explain temperature scales • State and explain zeroth law of thermodynamics
Heat (30 hours) • Specific heat capacity. • Heat and work. • First Law of Thermodynamics. • Transfer of heat. o Conduction. o Convection. o Radiation.	• Distinguish between heat and temperature • Calculate the heat content of various materials • Describe the different means of heat transfer • Analyze the use of heat energy • State and apply First Law of thermodynamics
Gases (25 hours) • Avogadro's number. • P-V diagrams. • Ideal and Real gases, • Adiabatic expansion	• Explain the relevance of Avogadro's number • Explain the properties of ideal and real gases • Use ideal gas equation and P-V-T diagrams to describe thermodynamic systems
Kinetic Theory (23 hours) • Mean free path. • Internal energy. • Specific heat constants.	• Analyze the motion of gas molecules such as mean free path • Calculate the kinetic energy of gas molecules
Heat Engines: (32 hours) • Second law of thermodynamics. • Carnot cycle. • Efficiency. Entropy.	• State and apply the Second Law of thermodynamics • Describe what is meant by entropy • Evaluate various energy cycles (e.g. Carnot cycle, Stirling engine, Refrigeration)

IX. Pre-assessment

Are you ready for this module?

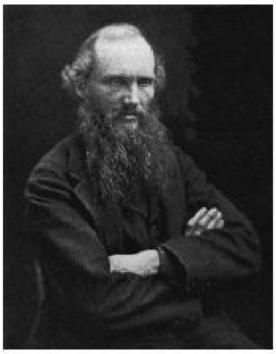


Figure 5
Lord Kelvin (1824-1907)

Dear Learners

In this section, you will find self-evaluation questions that will help you test your preparedness to complete this module. You should judge yourself sincerely and do the recommended action after completion of the self-test. We encourage you to take time and answer the questions.

Dear Instructors

The Pre-assessment questions placed here guide learners to decide whether they are prepared to take the content presented in this module. It is strongly suggested to abide by the recommendations made on the basis of the mark obtained by the learner. As their instructor you should encourage learners to evaluate themselves by answering all the questions provided below. Education research shows that this will help learners be more prepared and help them articulate previous knowledge.

9.1 Self Evaluation Associated With Thermal Physics

Evaluate your preparedness to take the module on thermal physics. If you score greater than or equal to 60 out of 75, you are ready to use this module. If you score something between 40 and 60 you may need to revise your school physics on topics of heat. A score less than 40 out of 75 indicates you need to learn school physics.

Try the following questions and evaluate where you are in topics related to thermal physics..

1. If the temperature of a patient is 40°C, his temperature on the Fahrenheit scale will be
   - (a) 104°F
   - (b) 72°C
   - (c) 96°C
   - (d) 100°C

2. A beaker is filled with water at 4°C. At one time the temperature is increased by few degrees above 4°C and at another time it is decreased by a few degrees below 4°C. One shall observe that
   - (a) the level remains constant in each case.
   - (b) in first case water flows while in second case its level comes down
   - (c) in second case water overflows while in first case it comes down
   - (d) water overflows in both cases.

3. Solids expand on heating because
   - (a) kinetic energy of atoms increases
   - (b) potential energy of atoms increases
   - (c) total energy of atoms increases
   - (d) the potential energy versus inter-atomic distance curve is a symmetric about the equilibrium distance and the inter-nuclear distance increases on heating.

4. On heating a liquid of coefficient of cubical expansion γ in a container having coefficient of expansion $\gamma / 3$, the level of liquid in the container will :
   - (a) rise.
   - (b) it is difficult to say
   - (c) will remain almost stationary
   - (d) fall

5. What is the value of absolute zero on the Fahrenheit scale?

(a) 0°F
(b) -22°F
(c) -350°F
(d) -459.4°F

6. Water is used to cool machines. this is mainly because

(a) It is cheap
(b) it has high specific heat capacity
(c) its heat of vaporization is greater than its specific heat capacity
(d) it is easily available.

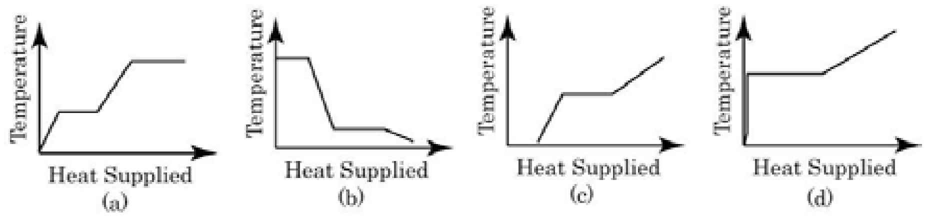
7. If 50 grams of ice and 50 grams of water are both at 0°C, then it is true that

(a) the water molecules have a higher average kinetic energy than the ice molecules
(b) the ice molecules have a higher average kinetic energy than the water molecules
(c) the water molecules have a higher total potential energy than the ice molecules
(d) the ice molecules have a higher total potential energy than the water molecules

8. Heat travels from one object to another when these objects differ in

(a) specific heat
(b) heat capacity
(c) temperature
(d) state

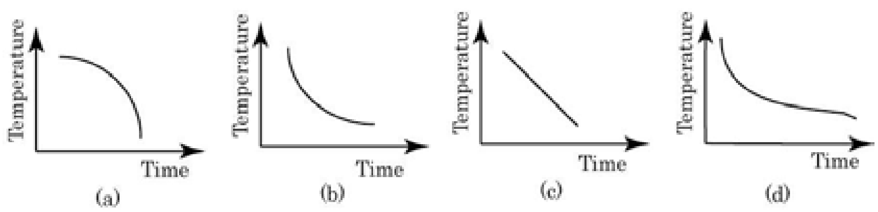
9. A block of ice at -10°C is slowly heated and converted to steam at 100°C. Which of the following curves represents the phenomenon qualitatively



10. The energy radiated by a black body per unit of time is proportional to the absolute temperature raised to the

   (a) first power
   (b) second power
   (c) third power
   (d) fourth power

11. A block of metal is heated to a temperature much higher than the room temperatue and allowed to cool in a room free from air currents. Which of the following curves correcltly represents the rate of cooling?



12. The heat conducted through a wall in a unit time is

   (a) is directly proportional to the thickness of the wall
   (b) is inversely proportional to the area of the wall
   (c) is directly proportional to the difference in temperature of the two surfaces of the wall
   (d) does not depend on the material in the wall

13. An adiabatic expansion of a gas is one in which

   (a) the pressure is kept constant
   (b) the volume is kept constant
   (c) the temperature is kept constant
   (d) it neither loses nor gains heat

14. If a Carnot engine operates between temperatures of 27°C and 127°C, its efficiency in percent is

   (a) 20
   (b) 25
   (c) 35
   (d) 50

15. Water always boils when

(a) its temperature reaches 100°C
(b) its vapor pressure is 1 gram per sq. cm
(c) its saturated vapor pressure equals the atmospheric pressure
(d) above which a gas cannot be liquefied

16. Equal volumes of gas at the same conditions of temperature and pressure

(a) contain the same number of molecules
(b) have the same density
(c) have the same mass
(d) have the same ionization potential

17. The coefficient of volume expansion (γ) surface expansion (β) and linear expansion (α) are related with each other as

(a) $\alpha = 2\beta = 3\gamma$

(b) $\gamma = 3\alpha = 2\beta$

(c) $\frac{\gamma}{3} = \frac{\beta}{2} = \alpha$

(d) $\gamma = 2\beta = 3\alpha$

18. A metallic ball having specific heat 0.22kcal/kg°C weighing 300g is to be converted into liquid at its melting point 660°C. If latent heat of the material of the ball is 76.8klcal/g how much heat is required in k cal for this? Initially the ball is at 20°C.

(a) 55.3
(b) 65.3
(c) 75.3
(d) 85.3

19. Which of the following statement is correct about heat capacity at constant pressure C_P and at constant volume C_V

(a) $C_P \leq C_V$

(b) $C_P \neq C_V$

(c) $C_P \geq C_V$

(d) All the above are possible depending upon the situtation

20. Which of the following statements is NOT true?
    (a) All reversible engines operaing between same two temperatures have same efficiency
    (b) No engine can be more efficient than carnot engine
    (c) Carnot engine is a reersible engine
    (d) Efficiency of a revesible engined depends on its working substance.

Figure 6
Carnot (1796-1832)

9.2 Answer Key

1. A
2. D
3. D
4. C
5. D
6. B
7. C
8. C
9. A
10. D
11. B
12. C
13. D
14. B
15. C
16. A
17. C
18. B
19. B
20. D

9.3 Pedagogical Comment For The Learner

Thermal physics differs somewhat from other branches of physics not only in its subject matter (very large systems), but also in its logical structure. There are no grand differential equations (like Maxwell's equations or the Schrodinger equation) that encompass the entire subject. Instead, there are only a few small equations, most of them definitions, together with a bag of tricks forsolving a huge variety of problems. Once the basic concepts are defined, almost everything follows from pure logic.

Because the logic of thermal physics is more important than any particular equations, you should concentrate on the logic, more than the equations, as you study. You'll need to understand, and be able to reproduce, most of the "derivations"; otherwise you will .find it difficult to apply the ideas to new systems that are different from those we discuss in this module. (The number of possible applications is so enormous that we'll have time for only a small fraction of them.)

Since the ideas of thermal physics are closely linked to each other, the material of this course will be highly sequential. It is therefore crucial that you follow the activities presented here in the sequence they appeared in the module. If you don't understand something go and refer to the compulsory materials and visit the useful links there in; don't just write it down and hope that you'll figure it out later.

Most important of all, do exercise and self assessments on schedule; don't put it off until the last minute (or later).

Extensive research in recent years has shown that the students who do best in physics (and other subjects) are those who involve themselves actively in the learning process. This involvement can take many forms: writing lots of questions in the margins of the module; asking questions by email; discussing physics in the AVU discussion forums etc.

A Final Word.....

Physics is not so much a collection of facts as a way of looking at the world. The author of this module hopes that this course will not only teach you many of the ideas of thermal physics, but will also improve your skills in careful thinking, problem solving, and precise communication. In this course you will gain lots of experience with qualitative explanations, rough numerical estimates, and careful quantitative problem solving. When you understand a phenomenon on all of these levels, and can describe it clearly to others, you are «thinking like a physicist» (as we like to say). Even if you eventually forget every fact learned in this course, these skills will serve you well for the rest of your life.

X. Key Concepts (Glossary)

Temperature: is a property of an object that indicates in which direction heat energy will flow if the object is placed in thermal contact with another object. Heat energy flows from an object at a higher temperature to the one at a lower temperature. The standard point in temperature measurement is the triple point of water which is arbitrarily assigned a value of 273.6 K. There are three commonly used scales of temperature.

a. Centigrade or Celsius Scale

lower fixed point = $0^{\circ}C$

Upper fixed point = $100^{\circ}C$

b. Fahrenheit Scale

lower fixed point = 32°

Upper fixed point = 180°

c. Reumer Scale

lower fixed point = 0°

Upper fixed point = $80^{\circ}C$

The three scales are related by:

$$\frac{C}{100} = \frac{R}{80} = \frac{F - 32}{180}$$

Zeroth law of Thermodynamics states that: If two bodies X and Y are each separately in thermal equilibrium with another object Z, then they are in thermal equilibrium with one another.. In the most common case the body Z is a thermometer.

Specific Heat Capacity: Is the heat energy required to raise unit mass of the substance through one Kelvin. The SI units are $J\,kg^{-1}\,K^{-1}$

Calorimetry: is a study concerned with heat measurements

Specific Latent Heat: Is the quantity of heat required to change unit mass of a solid to liquid, or liquid to gas, without change of temperature. *Specific latent heat of fusion* is the quantity of heat required to change unit mass of a substance from the solid state to the liquid state without change of temperature. *Specific latent heat of vaporization* is the quantity of heat required to change unit mass of a substance from the liquid state to the vapor state without change of temperature.

Newton's Law of Cooling: States that a body loses heat at a rate proportional to the difference in temperature between the body and the surroundings, provided that the temperature of the body is higher than the temperature of the surroundings.

Radiation: Is a process by which energy is transmitted by electromagnetic waves.

First Law of Thermodynamics: States that if a thermally isolated system is brought from one equilibrium state to another, the work necessary to achieve this change is independent of the process used.

Avogadro's Number: Is the number of elementary units in one mole of a substance. The Elementary unit may be an atom, molecule, ion, electron, photon, etc.

The Avogadro number can be stated as the number of atoms in $0.012\text{kg of}\ ^{12}C$.

The symbol given to Avogadro's number is N_A and it is given by

- $N_A = 6.02252 \times 10^{23}$

State: State describes the physical condition of a given sample of gas. Four quantities describe the state of a gas. These quantities are *temperature*, *pressure*, *volume* and *mass*.

Ideal Gas: Is a hypothetical gas with molecules of negligible size that exert no intermolecular forces

Kinetic Theory of Gases: Is a theory based on the assumption that all matter is made up of very small particles, in constant random motion that experience purely elastic collisions.

Cycles: Is a process in which a set of operations takes place in some particular order so that at the end of that set of operations initial conditions are restored. In the case of engines the working fuel may be in the form of a gas and after undergoing series of changes in pressure, volume and temperature returns to its original form.

Carnot Cycle: Is a cycle (of expansion and compression) of an idealized reversible heat engine that does work without loss of heat

Internal Energy: Is the energy which a system possesses. This energy depends upon the internal state of the system as determined by its pressure, temperature, and composition. The kinetic energy of motion of individual molecules or ions, the kinetic energy and potential energy of electrons and other particles within individual molecules or ions, contribute to the internal energy of the system. Work and heat are means of getting energy in and out of the system and so of changing the internal energy. It can be said that a change of internal energy (U) is equal to the heat (q) added to the system, less the work done (W) by the system:

- $U = q - W$

Entropy: Is a measure of the amount of disorder in a system; the more disordered the system, the higher the entropy. The disorder may be molecular chaos, e.g. when a liquid changes to a gas at the same temperature the entropy increases because the gas molecules are more disordered than the liquid molecules. Similarly a mixture of two gases has higher entropy than the two separate gases. An entropy change occurs when a system absorbs or evolves heat; the change in entropy is measured as the heat change divided by the temperature at which the change takes place; thus $dS = dq/T$, where dS is the entropy change. The entropy of a perfect crystal of each element or compound is given a reference value of zero at absolute zero of temperature

Heat Engine: Is a device that converts thermal energy into other forms of energy such as mechanical, electrical, etc. Heat engines are cyclic devices.

a. Heat is absorbed from a high temperature reservoir
b. Work is done by the engine
c. Heat is expelled by the engine to a lower temperature reservoir
d. The engine returns to its initial state

Second Law of Thermodynamics: States it is impossible for a self acting machine which is working in a cyclic process and is unaided by any external energy to convey heat from a body at a lower temperature to a body at a higher temperature. In other words heat can not flow from a cold body to a hot body without the aid of some external agency.

Thermodynamic Processes: are changes that taking place in a thermodynamic system. They are of two types:

a. Reversible Process: Is a process in which the change can be retraced in the reverse direction. All isothermal and adiabatic changes which are performed very slowly are examples of reversible process if in these changes it is assumed that no heat is lost in friction or to surrounding.
b. Irreversible Process: Is a process which can not be retraced . Work done against friction, heat due to flow of current through a conductor are examples of irreversible process.

Thermodynamic Processes: These can also be classified as:

a. Isothermal : Is a process that occurs at constant temperature
b. Isobaric : Is a process that occurs at constant pressure
c. Isovolumic: Is a process that occurs at constant volume
d. Adiabatic : Is a process that occurs without transfer of heat

XI. Compulsory Readings

Reading #1 About Temperature

Complete reference : http://dmoz.org/Science/Physics/Thermodynamics/

Abstract : The links on the above mentioned page lead you to html materials on topics of about temperature, applied thermodynamics, Fundamentals of thermodynamics, Thermodyanamics and its applications and many more that are directly relevant to this module.

Rationale: The Open Directory Project is the largest, most comprehensive human-edited directory of the Web. It is constructed and maintained by a vast, global community of volunteer editors.The list includes free online books Online book on Thermodynamics at UC Berkele, Lecture notes and problems from University of Pittsburg, Ideal Gas Law Applet illustrating the ideal gas law, action of a piston in a pressure chamber filled with ideal gas; Internal Combustion Engines Web Site in which Thermodynamics and heat transfer in Internal combustion engine. Applets are used to perform simple calculations. Developed at Colorado State University..

Date consulted: October, 2006

Reading #2 Thermodynamics

Complete reference http://www.lightandmatter.com/html_books/2cl/ch06/ch06.html

Abstract : The topics discussed in this document include Contents Pressure and Temperature; Microscopic Description of an Ideal Gas and Entropy

Rationale: This is one chapter of a free text book maintained by www.lightandmatter.com It is available in pdf and html formats. The pdf files can be downloaded chapter by chapter d potential; introduction to special relativity; Maxwell's equations, in both differential and integral form; and properties of dielectrics and magnetic materials

Date consulted: September, 2006

Reading #3 Internal Energy, Heat, Work & the First Law

Complete reference : http://www.shef.ac.uk/physics/teaching/phy203/lecture2.pdf

Abstract : Topics in this lecture notes are Internal energy of solids, liquids and gases. The contents are dealt under Heat and work; Functions of state; First Law of Thermodynamics and Heat capacities in terms of functions of state.

Special processes and Some useful mathematical relations are also provided.

Rationale: This is one of several second-term freshman physics courses offered at University of Shefield. It is geared towards students who are looking for a thorough and challenging introduction to thermal physics..

Date consulted: Nov, 2006

XII. Compulsory Resources

1. Source;Lon-CAPA

URL:-: http://lectureonline.cl.msu.edu/~mmp/kap10/cd283.htm.

Date Consulted:- August 2006

Description:- This Java applet helps you understand the effect of temperature and volume on the number of collisions of the gas molecules with the walls. In the applet, you can change the temperature and volume with the sliders on the left side. You can also adjust the time for which the simulation runs. The applet counts all collisions and displays the result after the run. By varying temperature and volume and keeping track of the number of collisions, you can get a good feeling of what the main result of kinetic theory will be.

2. Source;Uoregon University

URL:-: http://jersey.uoregon.edu/vlab/Piston/index.html

Date Consulted:-Nov 2006

Description:- This Java applet helps you to do a series of virtual experiments, you will control the action of a piston in a pressure chamber which is filled with an ideal gas. The gas is defined by four states: Temperature; Volume or density; Pressure and Molecular Weight There are 3 possible experiments to do. In the third experiment, labelled Ideal Gas Law, you can select from the Red, Blue or Yellow gas containers. Each gas in those containers has a different molecular weight and hence each will respond differently under changing pressure conditions..

3. Source: video.google.com

Complete Reference:- Computer calculation of Phase Diagrams. http://video.google.com/videoplay?docid=1397988176780135580&q=Thermodynamics&hl=en

Rationale: Thermodynamic models of solutions can be used together with data to calculate phase diagrams. These diagrams reveal, for a given set of all parameters (such as temperature, pressure, magnetic field), the phases which are thermodynamically stable and in equilibrium, their volume fractions and their chemical compositions. This lecture covers the pragmatic methods implemented in commercial software for the estimation of multicomponent, multiphase equilibria. The content should be generally useful to scientists. This is the fifth of seven lectures on the thermodynamics of phase transformations

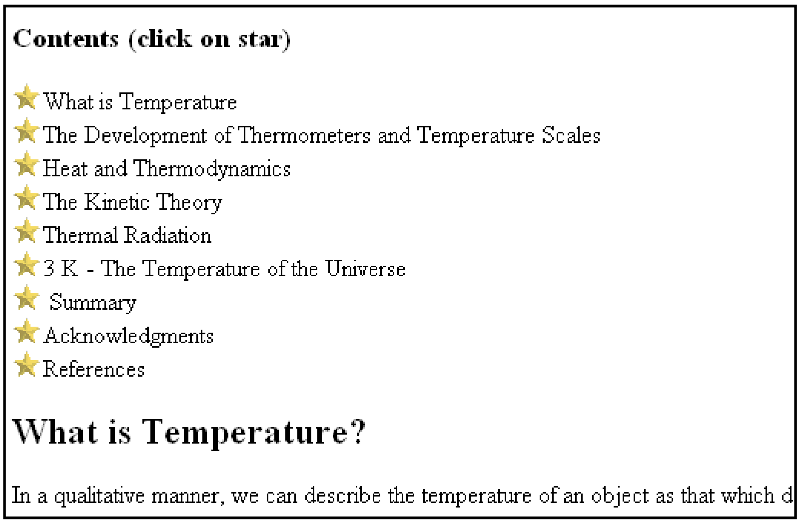
XIII. Useful Links

Useful Link #1

Title: About Temperature

URL: http://eo.ucar.edu/skymath/tmp2.html

Screen Capture:



Contents (click on star)

- What is Temperature
- The Development of Thermometers and Temperature Scales
- Heat and Thermodynamics
- The Kinetic Theory
- Thermal Radiation
- 3 K - The Temperature of the Universe
- Summary
- Acknowledgments
- References

What is Temperature?

In a qualitative manner, we can describe the temperature of an object as that which d

Description: There is an elementary description of temperature. The page is well illustrated and it may serve as a good starting point.

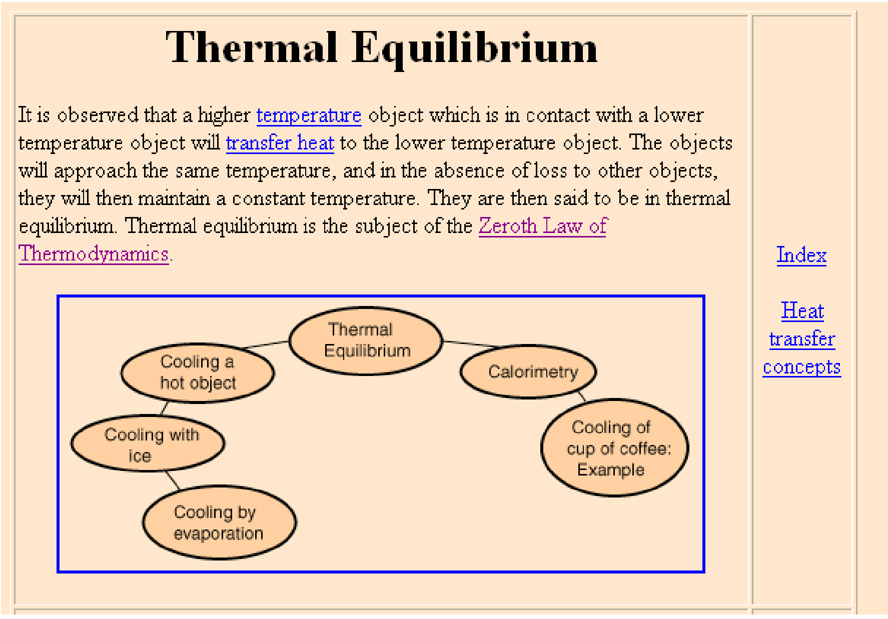
Rationale: A very basic (prepared for the middle school math teachers) tutorial but still useful for professionals.

Useful Link #2

Title: All Thermodynamics

URL: http://hyperphysics.phy-astr.gsu.edu/hbase/heacon.html#heacon

Screen Capture:



Description: All the required resources to study the second activity in the module are available here

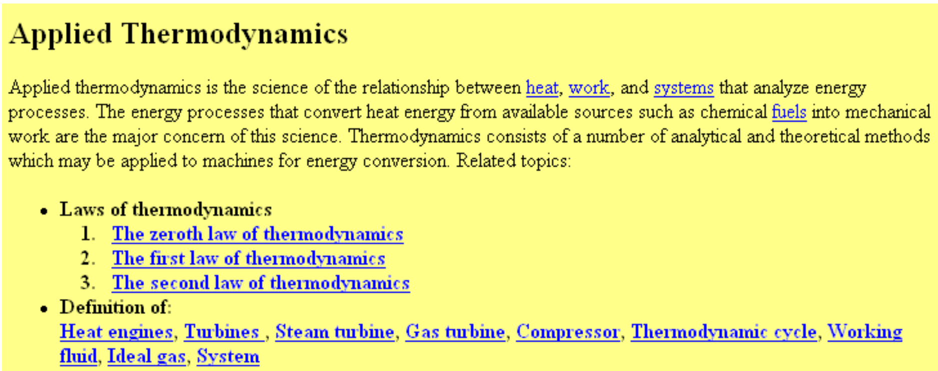
Rationale: This site has comprehensive coverage of most of physics, the creative use of multimedia and linking, and the impact it has had on students worldwide. Online tutorials cover a wide range of physics topics, including modern physics and astronomy. Material is organized through extensive concept maps

Useful Link #3

Title: Applied Thermodynamics

URL: http://www.taftan.com/thermodynamics/

Screen Capture:



Applied Thermodynamics

Applied thermodynamics is the science of the relationship between heat, work, and systems that analyze energy processes. The energy processes that convert heat energy from available sources such as chemical fuels into mechanical work are the major concern of this science. Thermodynamics consists of a number of analytical and theoretical methods which may be applied to machines for energy conversion. Related topics:

- Laws of thermodynamics
  1. The zeroth law of thermodynamics
  2. The first law of thermodynamics
  3. The second law of thermodynamics
- Definition of:
  Heat engines, Turbines , Steam turbine, Gas turbine, Compressor, Thermodynamic cycle, Working fluid, Ideal gas, System

Description: Definition and short explanations of terms, units and basic principles are given.

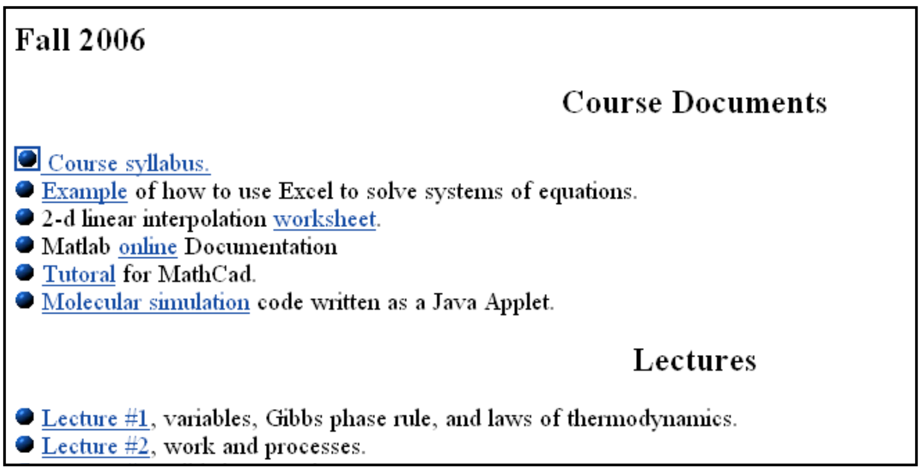
Rationale: This site serves as a revision to the concepts covered in this module.

Useful Link #4

Title: Fundamentals of Thermodynamics

URL: http://puccini.che.pitt.edu/~karlj/Classes/CHE2101/

Screen Capture:



Fall 2006

Course Documents

- Course syllabus.
- Example of how to use Excel to solve systems of equations.
- 2-d linear interpolation worksheet.
- Matlab online Documentation
- Tutoral for MathCad.
- Molecular simulation code written as a Java Applet.

Lectures

- Lecture #1, variables, Gibbs phase rule, and laws of thermodynamics.
- Lecture #2, work and processes.

Description: Lecture notes and problems from University of Pittsburg

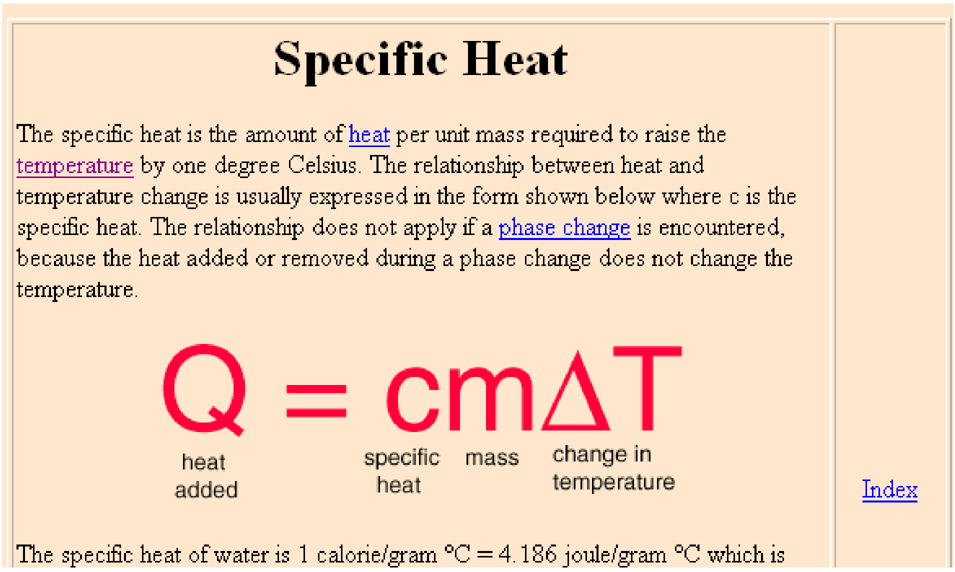
Rationale: This is an alternatively organized set of reference materials. Help learners to

Useful Link #5

Title: Specific Heat

URL: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/spht.html

Screen Capture:



Specific Heat

The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius. The relationship between heat and temperature change is usually expressed in the form shown below where c is the specific heat. The relationship does not apply if a phase change is encountered, because the heat added or removed during a phase change does not change the temperature.

$$Q = cm\Delta T$$

The specific heat of water is 1 calorie/gram °C = 4.186 joule/gram °C which is

Description: The site gives description of specific heat capacity

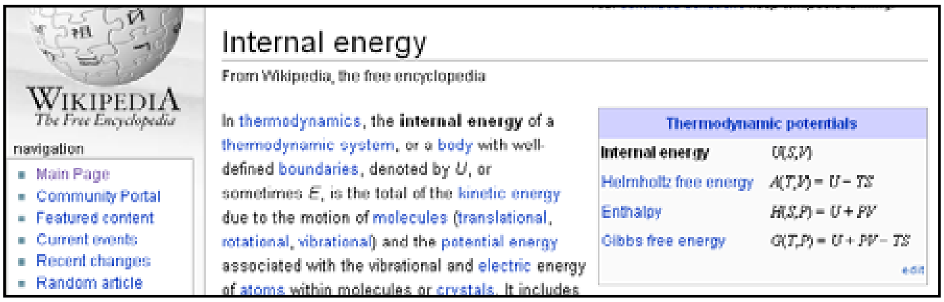
Rationale: There is online provision of calculating specific heat capacity according to the law of heat exchange. Enter the necessary data and then click on the active text above for the quantity you wish to calculate i.e. .the online facility gives you the answer.

Useful Link #6

Title: Internal Energy

URL: http://en.wikipedia.org/wiki/Internal_energy

Screen Capture:



Description: A detailed description and interactive content is available at this site. Related materials are a click away using the active links in the document

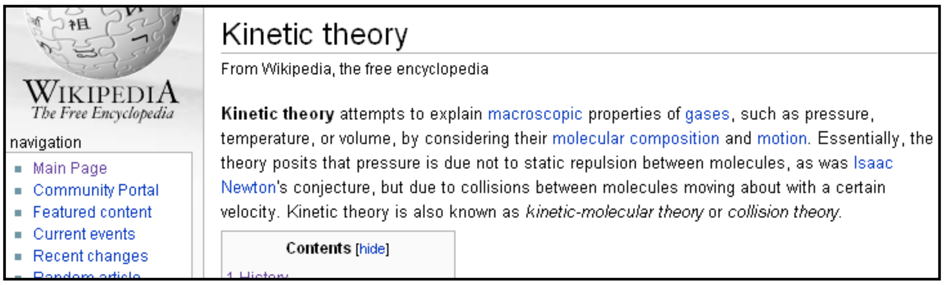
Rationale: Useful for the one who needs to compare many references.

Useful Link #7

Title: Kinetic theory

URL: http://en.wikipedia.org/wiki/Kinetic_theory

Screen Capture:



Description: This ling gives reading material suitable to beginners in the field as well as advance reading.

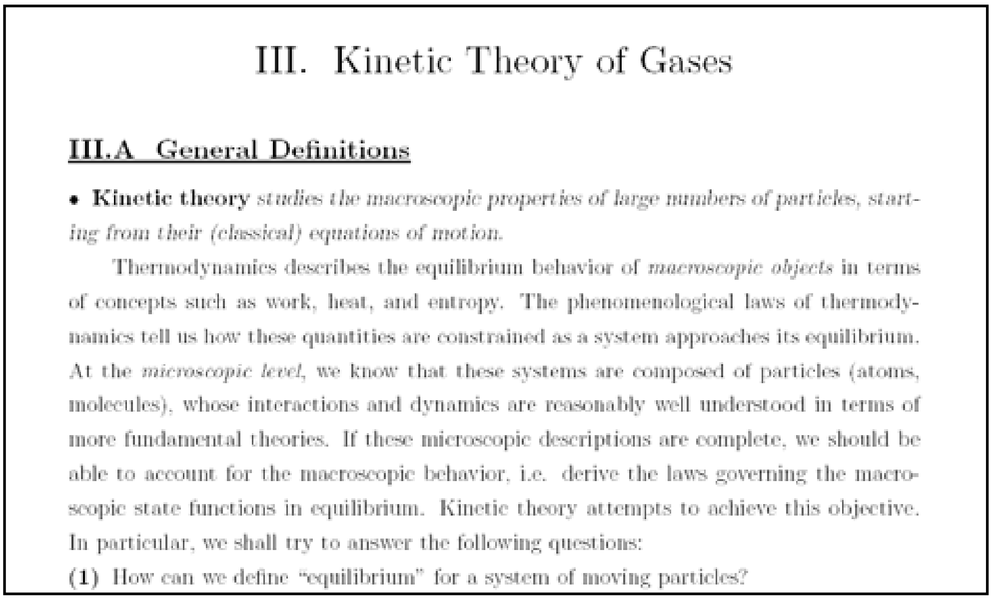
Rationale: Organized and regularly updated collection of articles.

Useful Link #8

Title: Kinetic Theory of Gases

URL: web.mit.edu/8.333/www/lectures/lec7.pdf

Screen Capture:



III. Kinetic Theory of Gases

III.A General Definitions

• **Kinetic theory** *studies the macroscopic properties of large numbers of particles, starting from their (classical) equations of motion.*

Thermodynamics describes the equilibrium behavior of *macroscopic objects* in terms of concepts such as work, heat, and entropy. The phenomenological laws of thermodynamics tell us how these quantities are constrained as a system approaches its equilibrium. At the *microscopic level*, we know that these systems are composed of particles (atoms, molecules), whose interactions and dynamics are reasonably well understood in terms of more fundamental theories. If these microscopic descriptions are complete, we should be able to account for the macroscopic behavior, i.e. derive the laws governing the macroscopic state functions in equilibrium. Kinetic theory attempts to achieve this objective. In particular, we shall try to answer the following questions:

(1) How can we define "equilibrium" for a system of moving particles?

Description: In this five page article A General Definitions is given and , Kinetic theory studies the macroscopic properties of large numbers of particles, starting from their (classical) equation of motion- ...

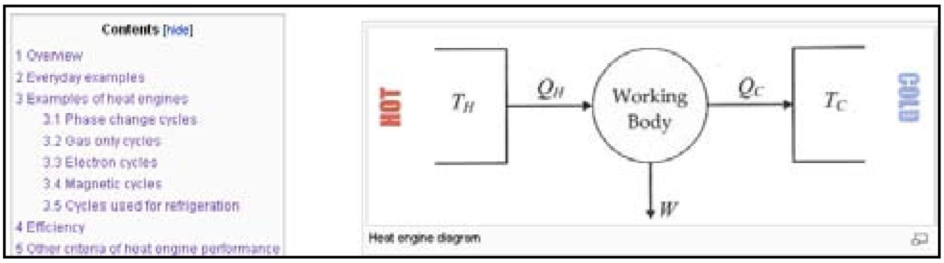
Rationale: This is a lecture prepared in MIT .open courseware material

Useful Link #9

Title: Heat Engines

URL: http://en.wikipedia.org/wiki/Heat_engines

Screen Capture:



Description: Different parameters of the heat engine are described from different perspectives.

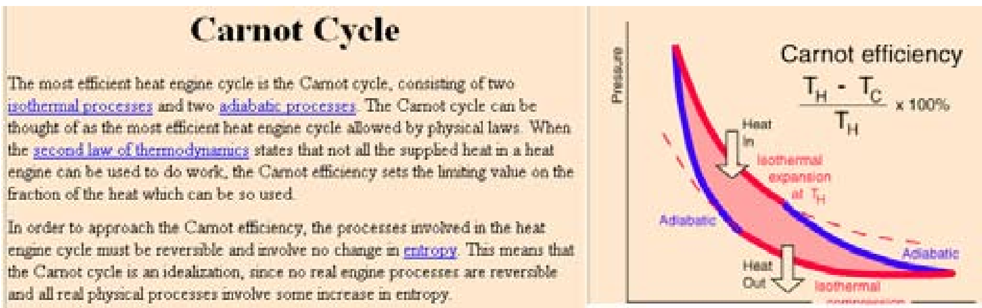
Rationale: This is a good reference material. to supplement activity five of this module.

Useful Link #10

Title: Carnot Cycle

URL: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/carnot.html

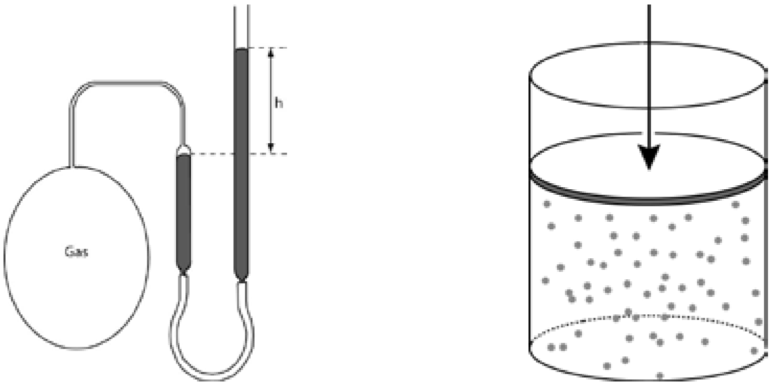
Screen Capture:



Description: This link Explains the basics of the Carnot cycle. Includes thermodynamic diagrams and theorems.

Rationale: Carnot cycle is the most efficient heat engine Carnot cycle, consisting of two isothermal processes and two adiabatic processes. The Carnot cycle can be thought of as the most efficient heat engine cycle allowed by physical laws.

XIV. Teaching And Learning Activities



a) b)

Figure 7
a) Constant volume gas thermometer b) : Constant pressure gas

Activity 1: Thermometry

You will require 10 hours to complete this activity. In this activity you are guided with a series of readings, Multimedia clips, worked examples and self assessment questions and problems. You are strongly advised to go through the activities and consult all the compulsory materials and as many as possible among useful links and references.

Specific Teaching and Learning Objectives

- Define temperature
- Explain temperature scales
- State and explain zeroth law of thermodynamics

Summary of the Learning Activity

Temperature and Temperature scales:

In this activity you will learn how various temperature scales are related to each other. You will also learn the relationship between temperature and the speed of the constituent atoms and molecules. You will also study how movements of atoms and molecules produce it. You will also observe three ways that heat energy can be transferred: by conduction, convection, and radiation. By participating in class activities, you will discover how and why the direction of heat moves from a warmer area to a cooler area. You will be introduced to formulas used to convert one temperature scale to another and how to use the specific heat of an object to find the change in energy of the object.

Key Concepts

Heat: Is the (sum) total internal kinetic energy of all the molecules in a given system of interest. (cup of coffee, bath tub, ocean).

Temperature: Is a measure of the average kinetic energy of the individual particles in an object.the average internal kinetic energy of the molecules in the region of interest.

Heat (internal kinetic energy): always flows from the hotter region (object) to the cooler region (object) for two regions/objects in direct contact (sensible heat exchange).

Fahrenheit scale: Is the temperature scale on which 32 and 212 are the temperatures at which water freezes and boils.

Celsius scale: Is the temperature scale on which zero and 100 are the temperatures at which water freezes and boils.

Kelvin scale: Is the temperature scale on which zero is the temperature at which no more energy can be removed from matter.

Absolute zero: Is the temperature at which no more energy can be removed from matter.

Degree: Is the unit of measurement of temperature.

Calorie: Is the amount of heat required to raise the temperature of one gram of water one degree Celsius.

List of Relevant Readings

Reference: Douglas D. C. Giancoli Physics for Scientists and Engineers. Vol. 2. Prentice Hall.

Abstract:

Rationale: This reading is a standard text book in many Universities and it provide easy sources of information. The contents have been treated in lucid manner with adequate mathematical support.

Reference: Raymond A. Serway (1992). Physics for Scientists & Engineers. Updated Version.

Abstract:

Rationale: This reading assumes Advanced Level/High School Physics background of the reader. The contents have been treated in lucid manner and it is probably the best at this level.

List of Relevant Resources

Reference http://jersey.uoregon.edu/vlab/Piston/index.html

Date Consulted:-Nov 2006

Description:- This Java applet helps you to do a series of virtual experiments, you will control the action of a piston in a pressure chamber which is filled with an ideal gas. The gas is defined by four states: Temperature; Volume or density; Pressure and Molecular Weight

Reference:-: http://lectureonline.cl.msu.edu/~mmp/kap10/cd283.htm.

Date Consulted:- August 2006

Description:- This Java applet helps you understand the effect of temperature and volume on the number of collisions of the gas molecules with the walls. In the applet, you can change the temperature and volume with the sliders on the left side. You can also adjust the time for which the simulation runs. The applet counts all collisions and displays the result after the run. By varying temperature and volume and keeping track of the number of collisions, you can get a good feeling of what the main result of kinetic theory will be.

Reference: video.google.com

Date Consulted: Nov 2006

Complete Reference:- Computer calculation of Phase Diagrams. http://video.google.com/videoplay?docid=1397988176780135580&q=Thermodynamics&hl=en

Rationale: Thermodynamic models of solutions can be used together with data to calculate phase diagrams. These diagrams reveal, for a given set of all parameters (such as temperature, pressure, magnetic field), the phases which are thermodynamically stable and in equilibrium, their volume fractions and their chemical compositions...

List of Relevant Useful Links

Title:- About Temperature

URL:- http://eo.ucar.edu/skymath/tmp2.html

Abstract:-This document was prepared for the middle school math teachers who are taking part in Project Skymath. It is provided a detailed description of temperature.

Title: A Brief History of Temperature Measurement

URL: http://thermodynamics-information.net/

Abstract: Brief biography and thermometers created by scientists from Réne Antoine Ferchault de Réamur (1683-1757) to William John Macquorn Rankine (1820-1872) are presented. There is also a table that compares the values of the Fahrenheit, Celsius, and Kelvin temperature for some common reference temperatures.

Title: Why do we have so many temperature scales?

URL: http://www.unidata.ucar.edu/staff/blynds/tmp.html

Introduction to the Activity

Qualitatively, we knew what is meant by hot and cold. We also know that a hot object when placed in contact with a cold object will cool, while the cold object gets warmer. To measure the degree of hotness or coldness of an object, there must be a method to associate a number to this attribute of objects. This number is called temperature of the object. There are a large number of ways in which a number may be associated with the property of hotness, but four of them are widely accepted and in this activity you will study how these scales are arrived at and their relationship.

Detailed Description of The Activity (Main Theoretical Elements)

*Insure clear learning guidance and variety of learning activities are provided throughout the acitvity.

Thermometry

Common-sense notions of heat and temperature are common to all of us. In physics, we need to define the notions of heat, temperature, work, etc. more carefully. Historically, it took a long time to arrive at the proper concept of 'heat'. The modern concept of heat accepts heat as a form of energy.

An important experiment regarding the concept of heat was due to Benjamin Thomson (also known as Count Rumford) in 1798. He observed that boring of a brass cannon generated a lot of heat, indeed enough to oil water. More significantly, the amount of heat produced depended on the work done but not on the sharpness of the drill. Former views of heat can not explain this observation and the most natural explanation was that heat was a form of energy.

Thermal Equilibrium

When we put two objects "in contact", the atoms in those objects can exchange energy. In doing so, some macroscopic (measurable) properties of the objects can change. If we wait long enough, those properties (actually, all the properties that one could measure) will be constant, and at that time we say that the objects are in thermal equilibrium with one another.

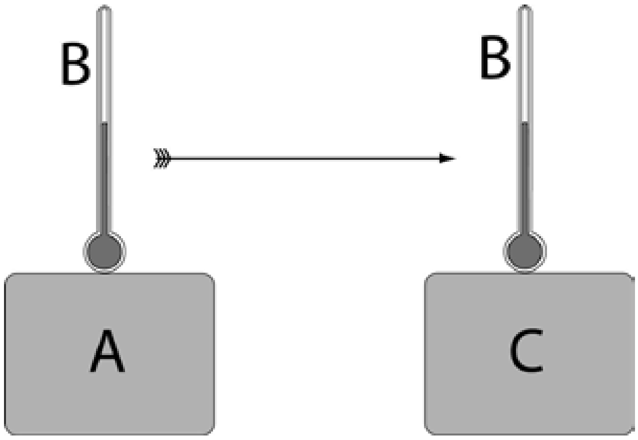


Figure 8
A and C are in thermal equilibrium with B. Therefore A and C are at the same temperature

The above statement is known as **Zeroth law of thermodynamics**. The Zeroth law allows us to know whether objects are at the same temperature, even when we can't place them in thermal contact and it allows temperature to become a reproducible and quantifiable concept. Notice that body B can be a thermometer as shown in the above diagram.

The Zeroth Law tells us that there is some property that is common to objects in thermal equilibrium. This property is temperature, and so the Zeroth Law is really telling us that temperature is a meaningful concept. Now we need a way to get a quantitative measure of temperature.

Temperature Scales and Thermometers

As discussed earlier, assigning values of temperature to different bodies is quite arbitrary i.e. a matter of choice provided we ensure that bodies in thermal equilibrium have the same value and those not in thermal equilibrium have un equal values of temperature. Thus, there are several possible temperature scales.

Temperature scales are constructed by choosing two fixed points: one to fix the origin of the scale and the other to fix the size of the unit of the scale. For example in the Celsius scale, the two fixed points are assigned the numbers 0^oC and 100^oC. On the other hand the two points in the Fahrenheit scale are 32^oF and 212^oF, thus both the origin and the unit size differ for the two scales.

Any thermometer makes use of some measurable property (called thermometric property) that change with temperature. This could be for example, length, volume, pressure, electrical resistance, thermoelectric e.m.f. radiated power, etc. Suppose we choose electrical resistance as the thermometric property. We first measure the resistance R_o and R_{100} of the resistance at the two fixed points of the Celsius scale. Then we put the resistance thermometer in contact with the body whose temperature is to be measured, and find its resistance to be R_t. We take the thermometric property (resistance) to change linearly with temperature. The temperature t_R of the body is then given by the linear relation:

- $$\frac{t_R}{100} = \frac{R_t - R_o}{R_{100} - R_0}$$

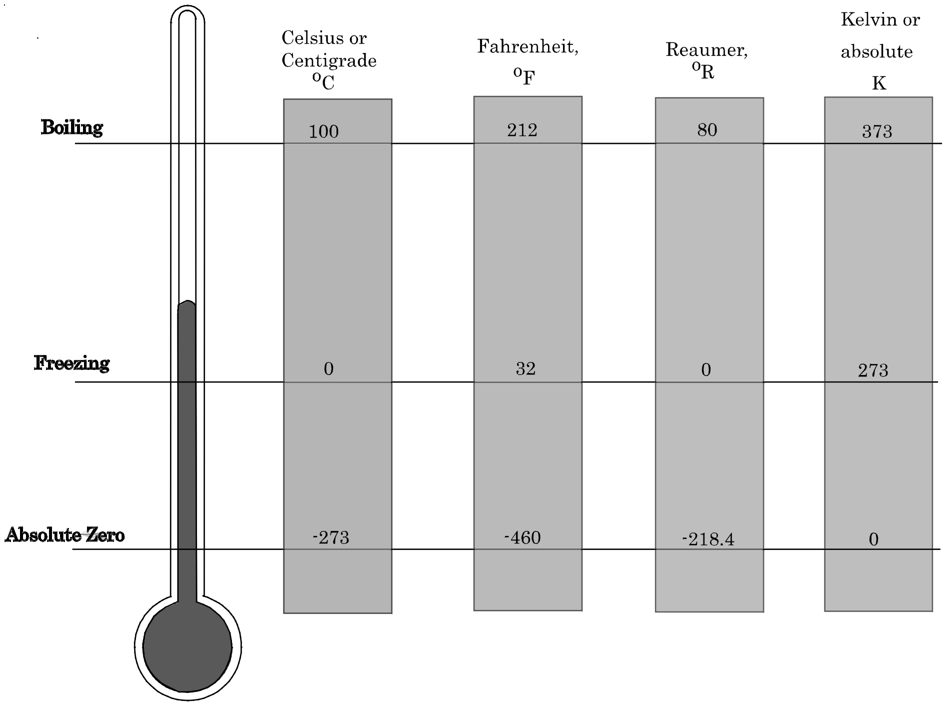


Figure 9
The three most common temperature scales.

A similar procedure can be followed for a thermometer that employs another thermometric porperty say thermoelectric electromotive force.

Let us look at liquid, gas, resistance, thermoelectric thermometers and pyrometers in more detail.

Liquid Thermometers: These thermometers are based on the principle of change in volume with change in temperature. Mercury and alcohol are common liquids used to construct thermometers. There are three scales (i) Centigrade (ii) Reaumer and (iii) Fahrenheit (F). If we have any thermometer marked Θ_o for ice point and having x divisions between boiling and freezing point we have for Θ temperature in such a scale

$$\frac{C}{5} = \frac{R}{4} = \frac{F-32}{9} = \frac{\Theta - \Theta_o}{x}$$

Kelvin or absolute scale $0^oC = 273.16K \approx 273K$. in general:

$$t^oC = t+273 \text{ Kelvin}$$

Gas Thermometers: Gas thermometers are of two types. Constant pressure and Constant volume thermometers.

Constant pressure gas thermometer is based on the principle that pressure remaining constant, the volume of a given gas varies directly as temperature i.e.

$$T = \frac{V_T - V_o}{V_o \gamma_P}$$

where $\gamma_P = 1/273$ is known as coefficient of cubical expansion of the gas.

Constant volume gas thermometer is based on the principle that when we heat a gas keeping the volume constant its pressure increases and when we cool the gas, its pressure decreases i.e.

$$T = \frac{P_T - P_0}{P_{100} - P_0} \times 100$$

where P_T, P_{100}, and P_0 denote pressure of a gas at constant volume at temperatures T^0C, 100^oC and 0^oC respectively

Platinium Resistance Thermometer: This thermometer works on the principle that electric resistance of metals increases more or less uniformly with temperature. If R_T and R_0 are the resistances of a give wire at $T\ ^0C$ and $0\ ^0C$ respectively then

$$R_T = R_0(1 + \alpha T)$$

where α is called *temperature coefficient of resistance*. The unknown temperature is calculated with the help of following relation

$$T = \left(\frac{R_T - R_0}{R_{100} - R_0}\right) \times 100$$

where R_{100} is the resistance of the wire at $100\,^0C$

Thermoelectric Thermometer: This thermometer works on the principle that: when two wires of different metals are joined end to end in a loop and the juncitons are kept at different temperatures, an e.m.f. is produced. The magnitude of this e.m.f. depends upon the difference of the temperature between the hot and cold junctions. By knowing the temperature of one junction and e.m.f. produced, the temperature of unknown body (in contact with other junction) can be known.

Pyrometers:-

1. Fery's Total Radiation Pyrometer: This pyrometer works on the principle that a hot body emits radiation and the amount of heat radiated at any time depends upon the temperature of the body. According to Stefan law total amount of heat radiated by a hot body per second per unit area is directly proportional to the fourth power of temperature.
2. Disappearing Filament Optical Pyrometer. This works on the principle that on heating the colour of a body changes due to change in temperature and the same colour when bodies have equal temperatures.

Learning Activities

*Reading assignments, Worked Examples, groupworks, experiments, hands on experiences…..

Task 1.1. Converting Fahrenheit to Celsius

The temperature of a room is 77^{o}F. what is the Celsius temperature of the room?
Solution Such problems are always solved in the following way:

- 77^{o}F is 77-32=45 Fahrenheit degrees above freezing.
- Since Fahrenheit degrees are larger than Celsius degrees, this temperature is only:
- $\left(\frac{5}{9}\right)\left(45\right)$ = 25 Celsius degress above freezing

But since freezing on the Celsius scale is 0^{o}C, this means the temperature is 25^{o}C

Task 1.2.Question for discussion

Discuss the following questions with your colleagues or on the discussion forum of AVU

1. Why does water kept in an earthen pot cool down when left in the veranda?
2. Explain why food takes long to cook at high altitude? Why does it get cooked faster in a pressure cooker?
3. Why moisture is deposited on the outside of a glass tumbler containing ice cold water?
4. Can water be made to boil without heating it? Can it be made to boil at $0^o C$? If yes how?
5. Why does steam cause more severe burn than water at the same temperature?

Task 1.3 Home made thermometer

Design and construct a thermometer at home. Report the procedure followed (i.e. materials used, fixing the lower and upper fixed points etc.) and the limitations of your thermometer.

Formative Evaluation 1

1. Define temperature.
2. How many temperature scales do you know? Explain each of them
3. State zeroth law of thermodynamics.
4. How does the zeroth law apply when you are measuring the temperature of you body using a themometer?
5. How will the pressure of a given mass of gas change as its volume increases four times?
6. Convert
   a. 98.4 °F to the Celsius scale
   b. 98.4 °F to the Kelvin scale
   c. 0 °F to the Celsius scale.
7. What temperature has the same numerical value on the Fahrenheit and Celsius scales?
8. Suggest a suitable method for measuring the temperature of the following, giving brief reasons for your choice.
   a. liquid nitrogen
   b. the body temperature of a living animal
   c. molten steel.
9. Wire made from a certain alloy has a resistance of $3(1+\alpha T^2)\ \Omega\ m^{-1}$, where T Kelvin is the gas scale temperature and α is a constant. A resistance thermometer made from the wire is calibrated at fixed points defined by melting ice and boiling water. By how much will it be in error with respect to the gas scale at a temperature of 50°C?

Teaching the Content in Secondary School 1

What interests students about temperature and temperature changes? This question is a good starting point to prepare a lesson on temperature and temperature scales. Students may be allowed to list their ideas about temperature and how it changes, and how it is converted between different temperature scales. This activity will give the teacher some information about learners' current knowledge and understanding of temperature. It will also tell something about what students do not know and how well they are able to pose interesting questions that can be answered mathematically.

With this inventory, it is possible to prepare a series of activities that will guide learners toward microscopic definition of temperature.

Activity 2: Heat

You will require 30 hours to complete this activity. In this activity you are guided with a series of readings, Multimedia clips, worked examples and self assessment questions and problems. You are strongly advised to go through the activities and consult all the compulsory materials and use as many as possible useful links and references.

Specific Teaching and Learning Objectives

- Distinguish between heat and temperature
- Explain heat capacity as a characteristic property of materials
- Calculate the heat content of various materials
- Describe the different mechanisms of heat transfer
- Analyze the use of heat energy
- Apply the first law of thermodynamics

Summary of The Learning Activity

The big idea in this activity centres on how to represent and analyze quantity of heat under different processes.

In the first section of the activity you will study the three ways by which heat is transferred, and be introduced to concepts like conductivity. In the second section, the amount of heat needed to raise a given mass by one degree is determined and heat capacity is defined. This activity is calumniated by relating the concept of work and heat and the gist of this is that heat is just a form of energy in transit from hot to cold object.

Key Concepts

System - In thermal physics the “thing” we’re interested in is usually called the “system” Everything else is called the “surroundings” For example in studying a mixture of ice in a calorimeter the calorimeter the water and the ice together form the system while the ambient air, the table on which the calorimeter is placed form the surrounding. In an automobile engine the burning gasoline and resulting gasses would compose the system. The pistons, block, radiator, outside air, etc. would be the surroundings.

Thermal Equilibrium:- when a system containing two or more objects in contact and at different temperature is left to itself the temperature of each object becomes the same after some time. This situation is known as thermal equilibrium.

Internal Energy - The internal energy of an object or physical system is the sum of the kinetic and potential energies of all the constituent atoms or molecules of the object or system. Potential energy arises from attractive/repulsive forces between atoms or molecules ("balls and springs" model) or from interaction of atoms/molecules with electric/magnetic fields, etc. Relative importance of PE and KE due to mutual interaction depends on phase of matter.

Heat: Is transfer of energy between objects as a result of a temperature difference between them. Notice that temperature of an object is associated with the kinetic energy of the constituent atoms/molecules and this motion of atoms/molecules is random. In other words heat is energy transfer associated with this random motion.

Work: In contrast to heat, which is energy transfer associated with random motion, work is energy transfer associated with directional, ordered motion of atoms/molecules. Compression/expansion of a substance, Application of magnetic field, Application of electric field, Flow of electric current are examples of work.

List of Relevant Readings

Reference: Kittel C. and Kroemer H., (1980) Thermal Physics, 2nd ed., W. H. Freeman and Co., San Francisco, CA..

Rationale: This classic reference on thermal physics is rcommended for a serious student of physics. The contents have been treated in detail with adequate mathematical support.

Reference: Nelkon & Parker (1995), Advanced Level Physics, 7th ed, CBS Publishers & Ditributer, 11, Daryaganji New Delhi (110002) India. ISBN 81-239-0400-2.

Rationale: This reading provide easy sources of information. The contents have been treated in lucid manner with adequate mathematical support.

List of Relevant Resources

Reference http://jersey.uoregon.edu/vlab/Piston/index.html

Date Consulted:-Nov 2006

Description:- This Java applet helps you to do a series of virtual experiments, you will control the action of a piston in a pressure chamber which is filled with an ideal gas. The gas is defined by four states: Temperature; Volume or density; Pressure and Molecular Weight

Reference:-: http://lectureonline.cl.msu.edu/~mmp/kap10/cd283.htm.

Date Consulted:- August 2006

Description:- This Java applet helps you understand the effect of temperature and volume on the number of collisions of the gas molecules with the walls. In the applet, you can change the temperature and volume with the sliders on the left side. You can also adjust the time for which the simulation runs. The applet counts all collisions and displays the result after the run. By varying temperature and volume and keeping track of the number of collisions, you can get a good feeling of what the main result of kinetic theory will be.

Reference: video.google.com

Date Consulted: Nov 2006

Complete Reference:- Computer calculation of Phase Diagrams. http://video.google.com/videoplay?docid=1397988176780135580&q=Thermodynamics&hl=en

Rationale: Thermodynamic models of solutions can be used together with data to calculate phase diagrams. These diagrams reveal, for a given set of all parameters (such as temperature, pressure, magnetic field), the phases which are thermodynamically stable and in equilibrium, their volume fractions and their chemical compositions...

List of Relevant Useful Links

Title: Heat Capacity

URL: http://en.wikipedia.org/wiki/Heat_capacity

Abstract: good article on electric charges is available

Introduction to the Activity

The laws that govern the relationships between heat and work is studied in thermal physics. Since heat is a form of energy and work is the mechanism by which energy is transferred, these laws are based on the basic principles that govern the behavior of other types of energy such as conservation of energy.

In this activity you will be guided through a series of tasks to understand heat as a form of energy and define terms like heat capacity, heat of fusion and heat of vaporization.

Detailed Description of The Activity (Main Theoretical Elements)

*Insure clear learning guidance and variety of learning activities are provided throughout the acitvity.

Heat

Heat is energy transferred between systems at different temperatures. When talking about heat, we usually use the symbol Q. The SI unit for heat is the *Joule*. However, more common units are *Btu* (British thermal unit) and *calories*:

1 Btu = 1055 J

1 cal = 4.186 J (1 Cal= 1,000 cal)

The internal energy of a body is the sum of the kinetic energies of molecules constituting the body. The potential energy is due to their interaction and the intermolecular energy (i.e. the energy of motion and interaction of atoms, nuclei, ions, etc.). The internal energy of a body depends neither on its motion as a whole nor on its potential energy in an external force field.

In this activity, we shall consider physical phenomena and processes which do not involve a change in the intramolcular energy. Hence, for the sake of convenience and simplicity, we shall treat the internal energy of a body as a sum of the kinetic energies of molecules constituting a substance and the potential energy of their interaction.

The internal energy of a body can be changed as a result of two kinds of effects on the body:

1. when work is done on the body (as a result of compression, extension and so on),
2. when heat is supplied to the body (heating a gas in a closed vessel, heating a liquid, etc.)

The transport of internal energy from one body to another without work being done by the bodies is called heat transfer. The amount of energy transported from body to body by heat transfer is called the amount of heat.

Transfer of Heat

The transfer of heat is normally from a high temperature body to a lower temperature body. Heat transfer changes the internal energy of both systems involved.

There are three ways heat energy can move from one place to another. These are *conduction, convection and radiation.*

Convection (in fluids)

Convection occurs when a gas or liquid has different temperatures within its boundaries. The fluid with the higher temperature is less dense than that with the lower temperature. The cooler fluid will sink and the warmer fluid will rise. This creates a mixing effect that moves heat energy from the bottom to all other areas of the fluid.

Figure 10
when water boils, hot water at the bottom rises to the top and cold water at the top sinks to the bottom.

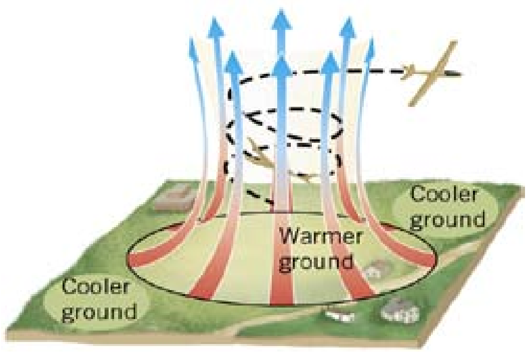


Figure 11
Heat from the sun warms the ground. The atmosphere is heated from the ground by convection

Convection currents in the atmosphere can create a low pressure area. This often happens in cities where the asphalt and concrete get hotter than the surrounding rural areas.

Sometimes the air above a region may be warmer than the air below. This is called an inversion layer because the temperatures are reversed from the normal situation. When this happens, convection does not occur and air pollution increases near the ground under the inversion. Los Angeles is notorius for this effect. Los Angeles lies in a depression between the mountains to the east and a slight ridge near the Pacific Ocean. Air pollution components can be trapped in this bowl shaped area for days.

Conduction (in gases, liquids, and solids)

Conduction is is the process of heat transfer through a substance without any motion of the material as a whole. Conduction can happen in solids, liquids and gasses, but is most noticeable in solids and to a lesser extent in liquids.

The process of conduction occurs as molecules that have been heated gain kinetic energy(speed up their random molecular motion) and collide with adjacent molecules giving them more kinetic energy. These newly energized molecules collide with their cooler neighbors giving them energy and the process is repeated until the entire object has been heated.

Different bodies have different thermal conductivities. Metals are particularly good conductors because they have some electrons that are not bound tightly and are able to transmit this energy of motion more easily than much larger molecules and atoms.

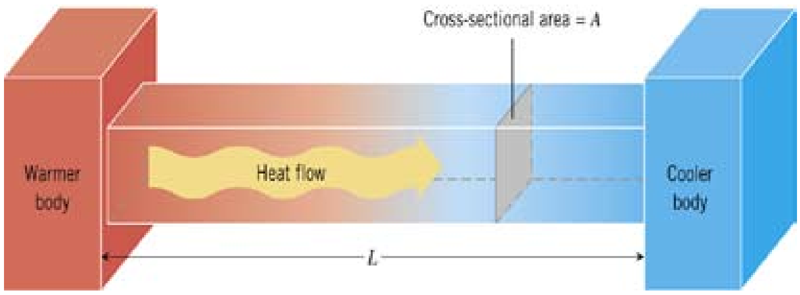


Figure 12
Heat conduction in solids

Thermal conductors allow heat to flow through them freely while thermal insulators do not. The amount of heat energy that flows through a substance depends on several factors. They are time, temperature difference, cross-sectional area, and length(distance).

The equation used to calculate the amount of heat energy that flows during a time t through a bar of cross-sectional area A with a temperature difference between the two ends of ΔT and length L is:

○ $$Q = \frac{kA\Delta T}{L}$$

k is a constant called the *thermal conductivity* of the substance and is large for conductors and very small for insulators.

Radiation:

Thermal radiation is the transfer of heat energy by electromagnetic waves. No medium is required. For example, the entire energy received by the Earth from the Sun is transferred by radiation.

All bodies emit some radiation. At lower temperatures, infrared is emitted and can be detected by special optical devices that convert infrared into visible light.

At about 1000 K the red glow associated with hot coals can be seen and at about 1700 K the mixture of frequencies called white light is seen.

The absorption and emission of radiation depends on the nature of the surface. Black, rough surfaces absorb and emit up to 97% of the incident radiation while smooth, silvery surfaces absorb and emit only about 10%.

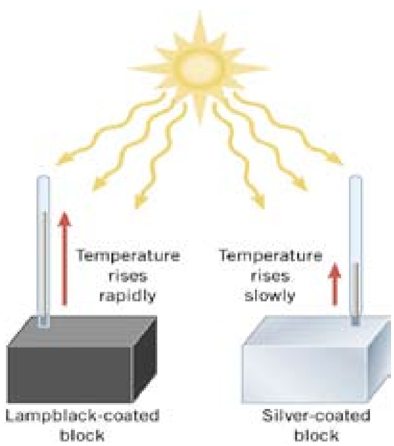


Figure 13
Heat is better absorbed by black bodies

Lampblack is a substance that is a strong absorber and emitter. In the diagram, most of the energy is absorbed by the lampblack coated block and then reemitted both outward and inward causing the internal temperature to rise. The silver coated block reflects most of the energy that strikes it and does not heat up as rapidly.

That is why we wear dark colors in winter and light colors in the summer. When the insulation for a building is being chosen, the rate of heat flow through the insulator can be calculated using the equation:

- $$\frac{Q}{t} = \frac{(A\Delta T)}{\left(L/k\right)}$$

L/k is called the R value of the insulation. It depends on the thickness L and the conductivity k k of the insulating material. High R values mean better resistance to heat flow and may be added to find the total R value of a multilayered wall or other surface.

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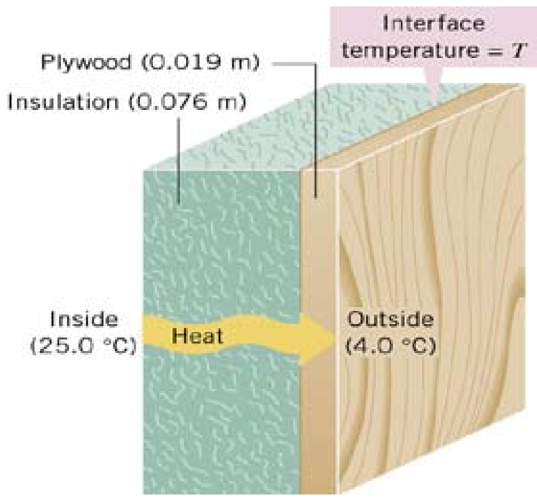

Figure 14
Heat conduction in solids

First Law of Thermodynamics

The law of conservation and transformation of energy is fudamental law of nature. It can be formulated as follows: *in all processes ocurring in nature, energy is not created or destroyed. It si transferred from one body to another or converted from one kind to another in eqivalent amounts*.

The work W done by the system during a transformation from an initial state to a final state depends on the path taken. The heat Q absorbed by the system during a transformation from an initial state to a final state depends on the path taken. However, the difference Q – W does not depend on the path taken! We define this quantity as the change in internal energy:

$$\Delta E_{int} = Q - W$$

The internal energy of a system increases if energy is added as heat, and decreases if energy is lost as work done by the system.

Heat Capacity

Heat capacity (C), like volume or mass, is a property that depends on the amount of material we are considering. It is the amount of heat that should be supplied to a body in order to raise its temperature by One Kelvin. In the SI units, heat capacity has the dimensions of a joule per kelvin.

A property that only depends on the substance (like density) is specific heat:

$$c = \frac{C}{m}$$

where m is the mass of the body.

The specific heat of water is $c = 1\text{cal/g}^\circ\text{C} = 4190\text{J/kgK}$ when a material undergoes a phase transformation (it is melting, or boiling), the temperature will not change, but heat is absorbed (or emitted) in the transformation. The energy per unit mass is called the heat of transformation L :

$$Q = Lm$$

Heat capacity depends on the condition of heating or cooling a body. For gases, the process of heating (cooling) at constant volume and at constant pressure are of special interest. In former case, we speak of the specific heat at constant volume (c_v), when the gas does not perform work, and the entire amount of heat supplied to it is spent to raise its internal energy: $Q_v = \Delta U$. In the latter case, the specific heat at constant pressure is meant (c_p). The gas heated at constant pressure expands, and a part of heat supplied to the gas is spent to do the work of expansion: $Q_p = \Delta U + A$. Hence we conclude that $Q_p > Q_v$, and the heat capacity at constant pressue is higher thant the heat capacity at constant volume:

$c_p > c_v$.

Heat and Work

Work Done in Compression/Expansion

Gas undergoes reversible compression by application of force F to frictionless piston as shown below.

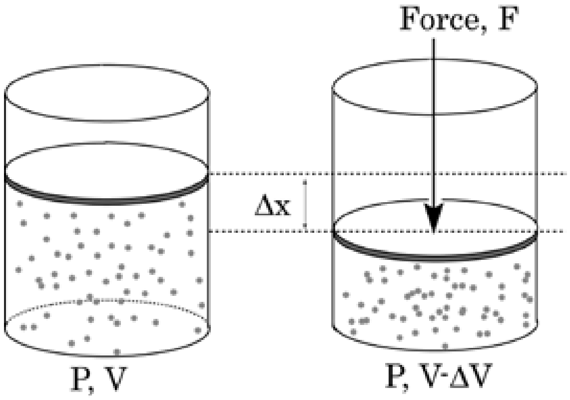

Figure 15
Reversible compression of gas molecules

Assume pressure of gas remains constant

$$\begin{aligned}\Delta W &= F\,\Delta x \\ &= (\text{pressure} \times \text{Area}) \times \Delta x \\ &= (\text{pressure} \times \text{Area}) \times \left(\frac{\text{Volume}}{\text{Cross sectional area (A)}}\right) \\ &= -P\Delta V\end{aligned}$$

In reality, pressure can/does vary during expansion/compression But pressure can be assumed to be constant in infinitesimal limit:

$$dW = -PdV$$

Calculate W for "large scale"processes by integration

$$W = -\int^{V_f} P(V)dV$$

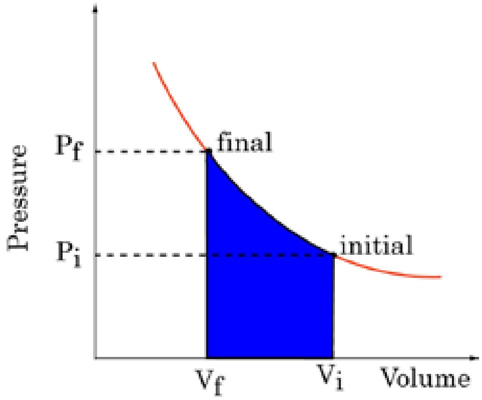

Figure 16
Work done on a gas is the equal to the shaded area.

Work Done is path dependent

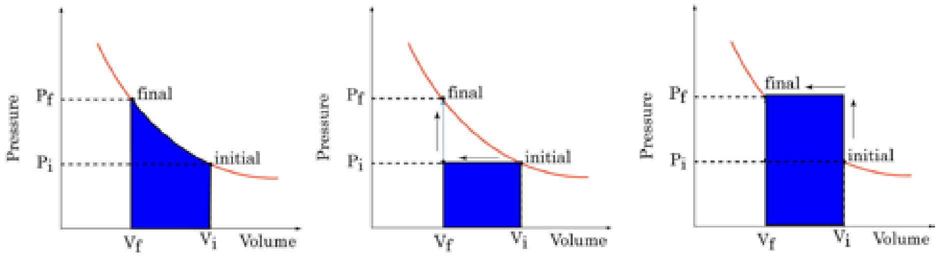

Figure 16
Work done is path dependent

The P-V plots above all represent changes between the same initial and final states. Clearly, the work done in each case is significantly different. Work done depends not only on initial and final states, but also on path taken between them.

Thermodynamic Functions of State

- We've seen that work done depends not only on initial and final states, but also on path taken between them
- Similar arguments can be applied to heat added /extracted (SerwayCh. 20).
- Therefore, heat and work do not have definite value corresponding to a particular state of a system.
- Some quantities, eg pressure, volume, temperature and internal energy do have definite values corresponding to a particular state. Changes in these variables are path independent only depend on final and initial states
- Pressure, volume, temperature, internal energy, etc are functions of state: heat and work are not

First Law of Thermodyanics:

$\Delta W = \Delta Q + \Delta U$

ΔU = increase in internal energy of system

ΔQ = heat added to system

ΔW = work done on a system

$\Delta U = U_{\text{final state}} - U_{\text{initial state}}$: independent of path

(even though ΔW, ΔQ are path dependent: U is a function of state

signs of the terms follow naturally if you remember just energy conservation

Learning Activities

Task 2.1. Experimental Determination of Specific Heat of a Substancee

The heat capacity of a body is determined with the help of a calorimeter and a thermometer. A simple calorimeter (see fig below) consists of a polished metallic cylinder placed into another metallic cylinder on corks (for thermal insulation)

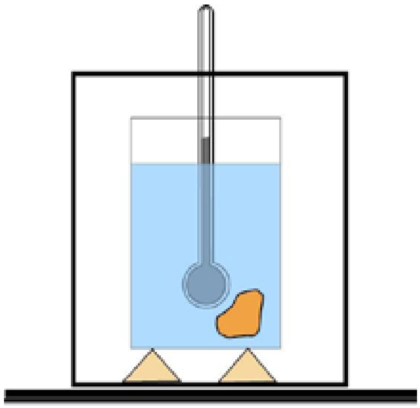

Figure 17
Calorimeter

The inner cylinder is filled with water or some other liquid of known specific heat. A body of mass *m,* and specific heat capacity *c,* heated to a certain temperature T is immersed in the calorimeter of mass m_1 and specific heat capacity c_1 in which the temperature is measured. Suppose that the temperature of the liquid of mass m_2, and specific heat capacity c_2, in the calorimeter is T' before the body is immersed in it, and when the temperatures of the liquid and the body are equal, the temperature becomes T_f .

From the law of conservation of energy and assuming the heat given away by the hot object Q, the heat taken away by water and the calorimeter the calorimeter to be respectively Q_1 and Q_2 respectively show that the specific heat capacity of the body is

$$c = \frac{c_1 m_1 (T_f - T') + c_2 m_2 (T_f - T')}{m(T - T_f)} = \frac{(c_1 m_1 + c_2 m_2)(T_f - T')}{m(T - T_f)}$$

Task 2.2.Exploring the amount of heat in a substance

When you grasp a piece of metal with your bare hand, it warms quickly. Would changing the mass of the metal make a difference? In this investigation, you are going to study the variables that can change the amount of heat which moves from body to another.

Equipment: For this activity you will need a balance, two styrofoam cups, a thermometer, a container at room temperature water and an immersion heater. **Warning**: Immersion heaters should never be plugged in if not immersed in water!!

Procedure

1. Find the mass of each of the styrofoam cups. Fill each cup with a different amount of water; find the mass of each cup and water.
2. Measure the temperature of the water in one of the cups. Submerge an immersion heater into the water in the cup. An immersion heater is a coil of nichrome wire encased in aluminum. It will provide equal amounts of heat when used for identical lengths of time. When you are ready to start timing a certain interval, plug in the immersion heater. Use the heater with care! Don't touch allow it to touch the sides of the cup or your experiment will be to find out how many paper towels it will take to clean up the water spilled. At the end of the interval, unplug the heater, remove it from the water and quickly find the temperature of the water in the cup.
3. Allow the immersion heater to cool to room temperature before using it in the next cup (why should you do this?). Repeat step two with the water in the second cup. Be sure to heat this water for the same length of time as you did the first cup. **Remember to unplug the heater before removing it from the water!**

Calculations

1. Calculate the mass of water in each cup.
2. Calculate the temperature change (ΔT) for each amount of water.
3. The calorie is defined to be the amount of heat required to change 1 gram of water by 1 Celsius degree. You can calculate the amount of heat absorbed by the water in each cup using the following equation:

$$\text{heat (in calories)} = \text{mass of water} \times \Delta T$$

Discussion

1. Compare the changes in temperature for each amount of water.
2. Based on your data, write a sentence to explain the effect the mass of water has on the temperature change when the same amount of heat is added.
3. Compare the amount of heat transferred into each cup by the immersion heater. What assumptions have you made in these calculations?

4. Consider repeating this experiment with cooking oil instead of water. What effects do you think this change would have on the results you obtained using the water?

Task 2.3. The Heat of Fusion of Ice

It is noted that the temperature remained constant while ice was melting. You learned that the heat supplied by immersion heater was raising the potential energy of the system. In this activity, you will determine the amount of heat required to melt one gram of ice at its melting point; this quantity is known as the heat of fusion of ice. Equipment- For this activity you will need a balance, a styrofoam cup, a thermometer, paper towels, warm water and some crushed ice.

Procedure

1. Find and record the mass of the styrofoam cup. Fill it half-way with warm (40-45 °C) water; then find and record the mass of the cup and water.
2. At the same time with one of your group performing step 1, another should contain some pieces of ice (about 1/3 of the volume of the water in the cup). Dry the ice as best as you can with the paper towel.
3. Find and record the temperature of the water in the cup. Then, slide the dried ice into the water. Stir the mixture with a stirrer and record the lowest temperature reached. If you use too much ice, the temperature will fall to 0°C and some ice will remain; should this happen, repeat the experiment with less ice.
4. Find and record the mass of the cup and cold water.

Calculations

1. Determine the mass of the warm water.
2. Determine the mass of the ice melted (mass of cold water - mass of warm water).
3. Calculate the temperature change (ΔT) of the warm water.
4. Calculate the temperature change of the melted ice. Assume that the initial temperature of the melted ice was 0°C.
5. Compute the heat lost by the warm water as it cooled. Remember: $Q = \text{mass} \times \Delta T \times 1.0\,\text{cal/g°C}$
6. Using the same formula, compute the heat gained by the melted ice as it warmed to the final temperature.
7. Note that the value obtained in (5) is larger than that in (6). What is the difference between these two values?
8. How do you account for this difference? The heat of fusion is expressed as cal / gram. What value did you obtain for the heat of fusion of ice?

9. Check with your instructor to obtain the accepted value for the heat of fusion of ice. Then, using the formula below, calculate your % error.

$$\% \text{ error} = \frac{|\text{experimental value - accepted value}| \times 100}{\text{accepted value}}$$

Formative Evaluation 2

1. A hollow was scooped out of a big block of ice and its interior dried with a cloth. A beaker containing 2.0 kg of hot water at 50 °C was then emptied quickly into the hollow. The water in the hollow was tipped out and its mass was found to be 3.25 kg. How much heat energy was required to melt the ice? How much energy would melt one kilogram of ice?

2. If a rocket service is instituted for intercontinental travel, the ship will rise with great speed through the Earth's atmosphere, make most of its trip in very thin air, then swoop down to its destination. If a passenger were to look at a thermometer hung on a passing floating balloon in space, he would find that it read –50 °C (especially if it were shaded from the sun). A thermometer hung just outside the ship would read:

   a. - 50 °C
   b. slightly less than (a)
   c. slightly more than (a)
   d. about 10,000 °C

3. Can heat energy be added to something without its temperature changing?

4. Temperature fluctuations are much less pronounced on land close to large bodies of water than they are in the central regions of large land masses. Explain this effect.

5. How much perspiration must evaporate from a 5.0 kg baby to reduce its temperature by 2 C°? The heat of vaporization of water at body temperature is about 580 cal/g.

6. As water falls from Niagara Falls, its temperature at the bottom of the falls will be:

   a. slightly higher
   b. slightly lower
   c. the same
   d. it depends on the air pressure

7. One piece of metal is at 0 °C. Another piece of metal is twice as hot. Its temperature is:

   a. 50 °C
   b. 273 °C
   c. 0 °C

8. If water had a lower specific heat, would ponds be more or less likely to freeze?
9. If you feel feverish, why can't you take your own temperature with your hand?
10. It's a cold, sunny day. You could wear a black or transparent plastic coat. If you want to stay warm, which should you wear?
11. You are stuck in a closed warm room. You notice an old refrigerator and discover that it is in good working order. If you turn it on and leave the door open, the room will:
    a. cool off
    b. warm up
    c. stay the same temperature
12. You are to bring cold water from a big pot to a boiler to cook some potatoes. To do it using the least amount of energy you should:
    a. turn the heat on full force
    b. put the heat on very low
    c. put the heat on at some medium value
13. The water is now boiling. To cook the potatoes using the least amount of energy you should:
    a. keep the heat on full force
    b. turn the heat way down so the water just barely keeps boiling
14. One tea kettle is heated directly over a stove flame and another is set upon a heavy piece of metal which is directly over a flame. After they both begin to whistle, you turn off the stove. Which of the following happens?
    a. The kettle heated directly over the flame continues to whistle, but the kettle resting on the metal stops promptly.
    b. The kettle on the metal continues to whistle, but the one heated directly stops promptly.
    c. Both stop whistling at the same time.
15. An ocean liner consumes a considerable amount of oil to heat its boilers to drive its propellers. Consider this energy-saving idea. Ocean water contains vast amounts of internal energy. What if a ship could pump in warm sea water, extract the heat from the water to heat its boilers, then discharge the cooled seawater back into the ocean? The discharged seawater may even be frozen if enough heat has been removed. Would this violate the conservation of energy? Could this idea work?

16. What is the distinction between internal energy and heat?
17. Does the concept of temperature apply to a single molecule?
18. Pots and pans are made of many different kinds of metal or combinations of metal (e.g., aluminum, copper, steel, iron, and nickel). If there is one kind of metal that is best for cooking, why do we still have such a variety?
19. A bathtub contains 150 kg of water at 20 °C. How much water at 65 °C must be added to provide a hot bath at 40°C?
20. You come in from a very hot day of hard work. You go to the freezer and pull out a tray of ice cubes. The heat has blistered your brain and you lick the ice cube tray. You discover to your dismay that your tongue is now stuck to the tray. As you're deciding what to do next, somebody knocks at the front door. Why did your tongue stick to the tray? How do you answer the door?

Teaching the Content in Secondary School 2

This activity introduces the concepts of thermal physics using microscopic point of view. It expands the concept of conservation of energy, and prepares students for the study of kinetic theory and gas laws presented in activity 3 and 4 of this module. The first law can be treated as an extension of the conservation of energy with heat defined as the transfer of energy by means of a diffeence in temperature.

The difference in specific heat capacity can be observed by heating a block of iron and an equal mass of water simultaneously over hot plates and observe the difference in temperature rise.

Activity 3: Gases

You will require 25 hours to complete this activity. In this activity you are guided with a series of readings, Multimedia clips, worked examples and self assessment questions and problems. You are strongly advised to go through the activities and consult all the compulsory materials and use as many as possible useful links and references.

Specific Teaching and Learning Objectives

- Explain the relevance of Avogadro's number
- State the properties of ideal and real gases
- Use ideal gas equation and P-V-T diagrams to describe thermodynamic systems

Summary of The Learning Activity

In this activity you will investigate the relationship between pressure, temperature, volume, and the amount of gas occupying an enclosed chamber. This activity consists of three sections. In section one amount of gas and the importance of Avogadro's number is discussed. In the second section the relationship between pressure and volume will be covered. In part three the relationship between pressure and volume as well the amount of gas present in a chamber will be determined. The results learnt in these tasks will be used to derive the Ideal Gas Law.

List of Relevant Readings for all activities

Reference:- Kittel C. and Kroemer H., (1980) Thermal Physics, 2nd ed., W. H. Freeman and Co., San Francisco, CA..

Rationale: This classic reference on thermal physics is recommended for a serious student of Physics. The contents have been treated in detail with adequate mathematical support.

Reference: Nelkon & Parker (1995), Advanced Level Physics, 7th ed, CBS Publishers & Distributer, 11, Daryaganji New Delhi (110002) India. ISBN 81-239-0400-2.

Rationale: This reading provides easy sources of information. The contents have been treated in lucid manner with adequate mathematical support.

List of Relevant Resources

Reference http://jersey.uoregon.edu/vlab/Piston/index.html

Date Consulted:-Nov 2006

Description: This Java applet helps you to do a series of virtual experiments, you will control the action of a piston in a pressure chamber which is filled with an ideal gas. The gas is defined by four states: Temperature; Volume or density; Pressure and Molecular Weight

Reference:-: http://lectureonline.cl.msu.edu/~mmp/kap10/cd283.htm.

Date Consulted:- August 2006

Description: This Java applet helps you understand the effect of temperature and volume on the number of collisions of the gas molecules with the walls. In the applet, you can change the temperature and volume with the sliders on the left side. You can also adjust the time for which the simulation runs. The applet counts all collisions and displays the result after the run. By varying temperature and volume and keeping track of the number of collisions, you can get a good feeling of what the main result of kinetic theory will be.

Reference: video.google.com

Date Consulted: Nov 2006

Complete Reference:- Computer calculation of Phase Diagrams. http://video.google.com/videoplay?docid=1397988176780135580&q=Thermodynamics&hl=en

Rationale: Thermodynamic models of solutions can be used together with data to calculate phase diagrams. These diagrams reveal, for a given set of all parameters (such as temperature, pressure, magnetic field), the phases which are thermodynamically stable and in equilibrium, their volume fractions and their chemical compositions...

List of Relevant Useful Links

Title: The P-V Diagram and Engine Cycles

URL: http://www.antonine-education.co.uk/Physics_A2/options/Module_7/Topic_4/topic_4.htm

Abstract: This site contains a good summary on Representation of processes on p – V diagram, Estimation of work done in terms of area below the graph, Expressions for work done are not required except for the constant pressure case, W = pDV , Extension to cyclic processes: work done per cycle = area of loop

Title: Avogadro's Number

URL: http://njsas.org/projects/atoms/avogadro.php

Abstract: A historic as well as scientific of the origin of Avogadro's number is presented on this page

Introduction to the Activity

The Ideal Gas Law describes the relationship between pressure, volume, the number of atoms or molecules in a gas, and the temperature of a gas. This law is an idealization because it assumes an "ideal" gas. An ideal gas consists of atoms or molecules that do not interact and that occupy zero volume.

A real gas consists of atoms or molecules (or both) that have finite volume and interact by forces of attraction or repulsion due to the presence of charges. In many cases the behavior of real gases can be approximated quite well with the Ideal Gas Law. and this activity focuses on the description of an ideal gas.

Detailed Description of The Activity (Main Theoretical Elements)

* Insure clear learning guidance and variety of learning activities are provided throughout the activity.

Gases

Avogadro's Number

The Mole

A mole (abbreviated mol) of a pure substance is a mass of the material in grams that is numerically equal to the molecular mass in atomic mass units (amu). A mole of any material will contain Avogadro's number of molecules. For example, carbon has an atomic mass of exactly 12.0 atomic mass units -- a mole of carbon is therefore 12 grams. For an isotope of a pure element, the mass number A is approximately equal to the mass in amu. The accurate masses of pure elements with their normal isotopic concentrations can be obtained from the periodic table.

One mole of an ideal gas will occupy a volume of 22.4 liters at STP (Standard Temperature and Pressure, 0°C and one atmosphere pressure).

$$\text{Avogadro's number } (N_A) = 6.0221367 \times 10^{23}\ /\text{mole}$$

Ideal and Real Gases

An ideal gas is defined as one in which all collisions between atoms or molecules are perfectly elastic and in which there are no intermolecular attractive forces. One can visualize it as a collection of perfectly hard spheres which collide but which otherwise do not interact with each other. In such a gas, all the internal energy is in the form of kinetic energy and any change in internal energy is accompanied by a change in temperature.

An ideal gas can be characterized by three state variables: absolute pressure (P), volume (V), and absolute temperature (T).

Two relationships were discovered that led to the formation of the ideal gas law. Boyle's Law relates volume and pressure. Boyle was able to show that volume and pressure are inversely related. This equation is commonly written:

$$P_1V_1 = P_2V_2 \qquad \text{Boyle's law}$$

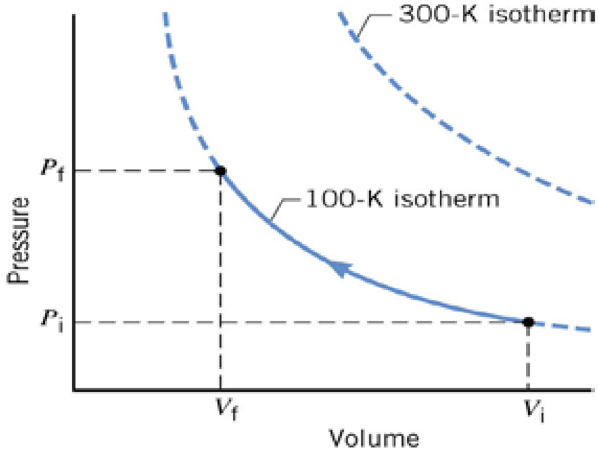

Figure18
Pressure and volume at two different temperatures.

The graph above shows the relationship between pressure and volume at two different temperatures. If the temperature is held constant as the pressure and volume vary the resulting curve is called an isotherm.

The other relationship is called Charles' Law and states that the volume of an ideal gas is directly proportional to its kelvin temperature. The equation is:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad \text{Charles' law}$$

If we keep the number of moles of the gas constant while allowing P, V, and T to change, we see that the expression (PV)/T must equal a constant.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

This relationship between state variables can also be deduced from the kinetic theory, as will be shown in the next activity.

$$PV = nRT = Nk_BT$$

where n = number of moles

R = universal gas constant = 8.3145 J/mol K

N = number of molecules

k_B = Boltzmann constant = 1.38066×10^{-23} J/K

= 8.617385×10^{-5} eV/K

$k_B = R/N_A$

N_A = Avogadro's number

= 6.0221×10^{23} /mol

This relationship is called the ideal Gas law

Standard Temperature and Pressure (STP)

STP is used widely as a standard reference point for expression of the properties and processes of ideal gases. The standard temperature is the freezing point of water and the standard pressure is one standard atmosphere. These can be quantified as follows:

Standard temperature: 0°C = 273.15 K

Standard pressure = 1 atmosphere

= 760 mmHg

= 101.3 kPa

Volume of 1 mole of an ideal gas at STP=22.4 liters

Example

In a gas thermometer, the pressure needed to fix the volume of 0.20 g of Helium at 0.50 L is 113.3 kPa. What is the temperature?

Solution:

In order to use the ideal gas law we need to find the number of moles for the given gas. Helium atom consists of 2 protons and 2 neutrons in the nucleus and therefore has a molar volume of 4g/mol. Therefore, we find

$$n = \frac{0.2\text{g}}{4\text{g/mol}} = 0.05\text{mol}$$

using this in the ideal gas equation and solving for the temprature T we obtain

$$T = \frac{pV}{nR} = \frac{113.3\text{n } 10^{3}}{0.05\text{mol} \text{n } 8.314\,\text{J/mol K}} = 136.3\,\text{K}$$

The temperature is 136 Kelvin.

PV Diagrams

Suppose a system starts from an initial state described by a pressure P_i, a volume V_f, and a temperature T_i. The final state of the system is described by a pressure P_f, a volume V_f, and a temperature T_f. The transformation from the initial state to the final state can be achieved in a variety of ways (see for example the figure below).In part (a) of the figure both pressure and volume change simultaneously. In part (b) the volume of the system is first lowered while keeping the pressure constant (this can for example be achieved by cooling the sample) and subsequently, the pressure is increased while keeping the volume constant (this can be achieved by heating the gas while increasing the pressure).

If the pressure of a gas increases it can move a piston (this happens in an engine). In this case, work is done by the system as the expanding gas lifts the piston. On the other hand, if we increase the weight of the piston, work will be done on the system as the piston falls. The force exerted by the gas on the piston is equal to PA, where A is the area of the piston and P is the gas pressure. If the piston is displaced by a distance dS, the amount of work done can be calculated as follows:

$$dW = F \cdot ds = (PA)ds = pdV$$

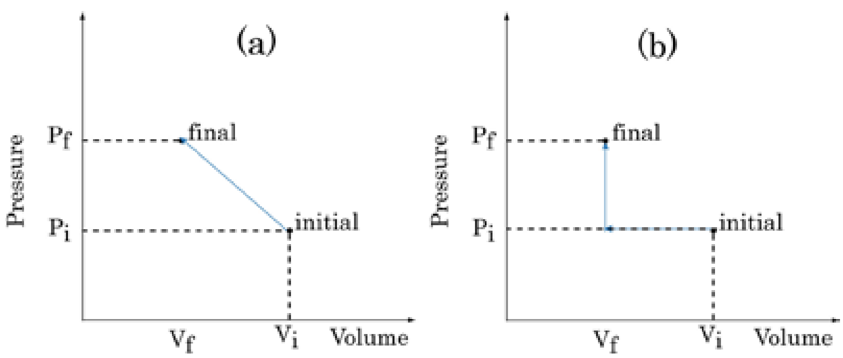

Figure19
Two possible ways to get from one state of a system to anther.

The total work done during a finite displacement of the piston is now easy to calculate

$$W = \int dW = \int_{V_i}^{V_f} P\,dV$$

If W is positive, work was done by the system (for example, when the expanding gas lifts the piston). A negative value of W tells you that work was done on the system (the piston is pressed down in order to compress the gas).

The amount of work done is equal to the area under the curve in the pV diagrams shown in the Figure above. Clearly, the amount of work done depends on the path chosen. The work W for the path shown in Figure a is significantly more than the work W for the path shown in Figure (b). Any change in the system in which the volume does not change will not produce/cost any work. The work done for the paths shown in Figure (a) can be calculated easily:

$$W_a = \int_{V_i}^{V_f} \left(\frac{P_i - P_f}{V_i - V_f}(V - V_f) + P_f \right) dV = \frac{1}{2}\left(P_i + P_f\right)(V_f - V_i)$$

No work is done for the path shown in Figure (b) between (p_i, V_i) and (p_f, V_i) since there is no change in volume. The work done to move from (p_f, V_i) to (p_f, V_f) is calculated easily

$$W_b = \int_{V_i}^{V_f} P\,dV = \int_{V_i}^{V_f} P_f\,dV = P_f\left(V_f - V_i\right)$$

Clearly, W_b is always less then W_a, and we can make the amount of work done as small or as large as we want. For example no work would be done if the transition follows the following path:

$$\left(P_i, V_i\right) \to \left(0, V_i\right) \to \left(0, V_f\right) \to \left(P_f, V_i\right)$$

A system can be taken from a given initial state to a given final state by an infinite number of processes. In general, the work W and also the heat Q will have different values for each of these processes. We say that heat and work are path-dependent quantities.

From the previous discussion neither Q nor W represents a change in some intrinsic properties of the system. Experimentally, however, it is observed that the quantity Q - W is the same for all processes. It depends only on the initial and final states and it does not matter at what path is followed to get from one to the other. The quantity Q - W is called the change in the internal energy U of the system:

$$\Delta U = U_f - U_i = Q - W$$

This equation is called the first law of thermodynamics. For small changes the first law of thermodynamics can be rewritten as:

$$dU = dQ - dW$$

Adiabatic Processes

If a system is well insulated, no transfer of heat will occur between it and its environment. This means that Q = 0, and the first law of thermodynamics shows that

$$\Delta U = -W$$

If work is done by the system (positive W) its internal energy decreases. Conversely, if work is done on the system (negative W) its internal energy will increase. For gases, the internal energy is related to the temperature: a higher internal energy means a higher temperature. Adiabatic expansion of a gas will lower its temperature; adiabatic compression of a gas will increase its temperature.

Constant Volume Processes

If the volume of a system is held constant, the system can do no work (W = 0J). The first law of thermodynamics then shows that

$$\Delta U = Q$$

If heat is added to the system its internal energy will increase; if heat is removed from the system its internal energy will decrease.

Cyclical Processes

Processes which, after certain interchanges of heat and work, are restored to their initial state are called cyclical processes. In this case, no intrinsic properties of the system are changed, and therefore $\Delta U = 0$. The first law of thermodynamics now immediately yields

$$Q = W$$

Free Expansion

Free expansion is an adiabatic process in which no work is done on or by the system. This means that $Q = W = 0J$, and the first law of thermodynamics now requires that

$$\Delta U = 0J$$

Learning Activities

Task 3.1. Using the Ideal Gas Equation

A cylinder having a volume of 200 litres contains oxygen at a temperature T=20 ^{o}C and pressure 10^7Pa. Show that this amount of oxygen occupies 18.6m^3

Task 3.2.Work Done by a piston

A cylinder contains a gas and closed by a movable piston. The cylinder is kept submerged in an ice water mixture. The piston is quickly pushed down from position a to position b and then held at position b until the gas is again at the temperature of the ice water mixture; it then is slowly raised back to position a.

a) Draw a p-V diagram for the process.
b) If 140 g of ice is melted during the cycle, show that 46600J of work has been done on the gas.

Formative Evaluation 3

1. Given the following sets of values, calculate the unknown quantity
   - i. a) V=?.
     1. P = 1.01 atm
     2. n = 0.00831 mol
     3. T = 25°C
   - ii. b) P = ?
     1. V= 0.602 L
     2. n = 0.00801 mol
     3. T = 311 K
2. At what temperature would 2.10 moles of N_2 gas have a pressure of 1.25 atm and in a 25.0 L tank?
3. When filling a weather balloon with gas you have to consider that the gas will expand greatly as it rises and the pressure decreases. Let's say you put about 10.0 moles of He gas into a balloon that can inflate to hold 5000.0L. Currently, the balloon is not full because of the high pressure on the ground. What is the pressure when the balloon rises to a point where the temperature is -10.0°C and the balloon has been completely filled with the gas.

4. What volume is occupied by 5.03 g of O_2 at 28°C and a pressure of 0.998atm?
5. Calculate the pressure in a 212 Liter tank containing 23.3 kg of argon gas at 25°C?.

Optional Formative Evaluation 3

1. If you were to take a volleyball scuba diving with you what would be its new volume if it started at the surface with a volume of 2.00L, under a pressure of 752.0 mmHg and a temperature of 20.0°C? On your dive you take it to a place where the pressure is 2943 mmHg, and the temperature is 0.245°C.
2. What is the volume of 1.00 mole of a gas at standard temperature and pressure?
3. A 113L sample of helium at 27°C is cooled at constant pressure to -78.0°C. Calculate the new volume of the helium.
4. What volume of He is occupied by 2.35 mol of He at 25°C and a pressure of 0.980 atm?
5. An aerosol can contains 400.0 ml of compressed gas at 5.2 atm pressure. When the gas is sprayed into a large plastic bag, the bag inflates to a volume of 2.14 L. What is the pressure of gas inside the plastic bag?

Activity 4 : Kinetic Theory of Gases

You will require 23 hours to complete this activity. In this activity you are guided with a series of readings, Multimedia clips, worked examples and self assessment questions and problems. You are strongly advised to go through the activities and consult all the compulsory materials and use as many as possible useful links and references.

Specific Teaching and Learning Objectives

- Analyse the motion of gas molecules such as mean free path
- Calculate the energy content of gases
- Summarise of The Learning Activity

Key Concepts

The temperature of a gas can be related to the internal motion of the molecules.

The ideal gas approximation yields: $PV = \frac{2}{3} N \overline{KE}$, where $\overline{KE}$ is the mean kinetic energy of an individual molecule and N is the total number of molecules in the gas.

The internal energy U of a gas is defined as $U = N\overline{KE}$ and thus $PV = \frac{2}{3}U$
The relation between the mean kinetic energy and the temperature is given by

$$KE = \frac{3}{2} KT$$

whre $K = R / N_A$ is the Boltzmann constant:

List of Relevant Readings for all activities

Reference: Kittel C. and Kroemer H., (1980) Thermal Physics, 2nd ed., W. H. Freeman and Co., San Francisco, CA..

Abstract:

Rationale: This classic reference on thermal physics is rcommended for a serious student of physics. The contents have been treated in detail with adequate mathematical support.

Reference: Nelkon & Parker (1995), Advanced Level Physics, 7th ed, CBS Publishers & Ditributer, 11, Daryaganji New Delhi (110002) India. ISBN 81-239-0400-2.

Abstract:

Rationale: This reading provides easy sources of information. The contents have been treated in lucid manner with adequate mathematical support.

List of Relevant Resources

Reference http://jersey.uoregon.edu/vlab/Piston/index.html

Date Consulted: Nov 2006

Description:- This Java applet helps you to do a series of virtual experiments, you will control the action of a piston in a pressure chamber which is filled with an ideal gas. The gas is defined by four states: Temperature; Volume or density; Pressure and Molecular Weight

Reference:-: http://lectureonline.cl.msu.edu/~mmp/kap10/cd283.htm.

Date Consulted: August 2006

Description:- This Java applet helps you understand the effect of temperature and volume on the number of collisions of the gas molecules with the walls. In the applet, you can change the temperature and volume with the sliders on the left side. You can also adjust the time for which the simulation runs. The applet counts all collisions and displays the result after the run. By varying temperature and volume and keeping track of the number of collisions, you can get a good feeling of what the main result of kinetic theory will be.

Reference: video.google.com

Date Consulted: Nov 2006

Complete Reference:- Computer calculation of Phase Diagrams. http://video.google.com/videoplay?docid=1397988176780135580&q=Thermodynamics&hl=en

Rationale: Thermodynamic models of solutions can be used together with data to calculate phase diagrams. These diagrams reveal, for a given set of all parameters (such as temperature, pressure, magnetic field), the phases which are thermodynamically stable and in equilibrium, their volume fractions and their chemical compositions...

List of Relevant Useful Links

Title: Kinetic Theory of Gases: A Brief Review

URL: http://galileo.phys.virginia.edu/classes/252/kinetic_theory.html

Abstract: This Brief Review by Michael Fowler of University of Virginia.presents a series of lectures on Physics . There are links to previous lectures and webpages too.

Title: Kinetic Theory of Gasess: Encyclopedia Britannica

URL: http://www.britannica.com/eb/article-9045492/kinetic-theory-of-gases

Abstract: A detailed description of the kinetic theory is available at Britannica. com

Introduction to the Activity

The gas laws described in activity 3 were found by experimental observation, but Boyle's law and Charles' law are not obeyed precisely at all pressures. A gas which did obey these above laws perfectly at all pressures would be a "perfect" or "ideal" gas, and the kinetic theory resulted from an attempt to devise a mechanical model of such a gas based on Newton's laws of motion.

Detailed Description of The Activity (Main Theoretical Elements)

*Insure clear learning guidance and variety of learning activities are provided throughout the acitvity.

The Kinetic Theory of Gases

Basic Assumptions of the Kinetic Theory

The kinetic theory of matter forms the basis of our understanding of how a gas behaves. The four basic assumptions of the kinetic theory are:

1. The molecules in a gas are identical minute spherical particles, continuously moving in random directions in straight lines between collisions with one another or with the walls of their container.
2. The time taken in collisions is negligible and no energy is lost during a collision (i.e. the collision is elastic).
3. The molecules are negligible in size compared with the volume of the container.
4. There are no mutual forces of attraction or repulsion between the molecules, or between molecules and container.

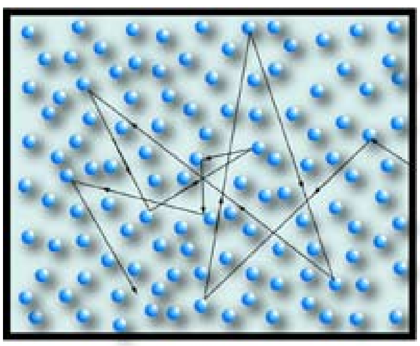

Figure 20
Random motion of gas molecules

Kinetic Interpretation of Pressure

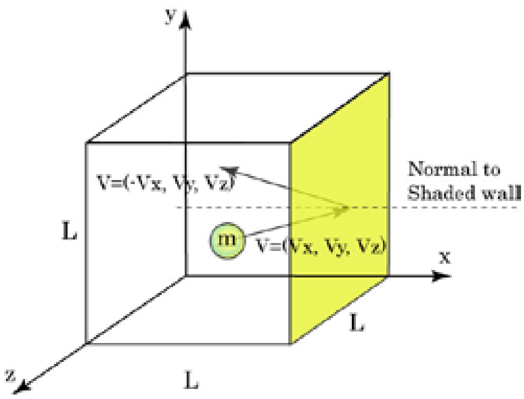

Figure 21
The force exerted per unit area by many particles of a gas randomly striking the walls of the container is called pressure

Consider a gas enclosed in a cube of side L. Take the axes to be parallel to the sides of the cube as shown in the above figure. A molecule with velocity (v_x, v_y, v_z) hits the planar wall of area $A=L^2$. Since the collision is elastic, the molecule rebounds with the same velocity; its y and z components of velocity do not change in the collision but the x - component reverses sign. That is, the velocity after collision is $(-v_x, v_y, v_z)$. The change in momentum of the molecule is $-mv_x - (mx_x) = -2mv_x$. By the principle of conservation of momentum, the momentum imparted to the wall in the collision is $2mv_x$.
The pressure is derived from the relationship

Force = Rate of change of momentum

As the molecules collide with a wall of the container, they change dirction from going towards it to going away from it; their momentum is altered just as if the wall wser applyig a force towards the inside of the container. The gas pressure is equal and opposite to this force per unit area of the wall.

In a small time interval Δt, a molecule with x-component of velocity v_x will hit the wall if it is within the distatce $v_x \Delta t$ from the wall. That is, molecles within the volume $Av_x \Delta t$ only can hit the wall in time Δt. But, on the average, half of it are moving towards the wall and the other half away from the wall. Thus the number of molecules with velocity (v_x, v_y, v_z) hitting the wall in time Δt is

$$\frac{1}{2} A v_x \Delta t\, n$$

where n is the number of molecules per unit volume.. The total momentum transferred to the wall by thes molecules in time Δt is :

$$P = (2mv_x)\left(\frac{1}{2} n A v_x \Delta t\right)$$

The force on the wall is the rate of momentum transfer $P/\Delta t$ and pressure is force per unit area:

$$P = \frac{Q}{A\Delta t} = nmv_x^{\,2}$$

In actual fact, all molecules in a gas do not have the same velocity; there is a distribution of velocities. The above equation therefore stands for pressure due to the group of molecules with speed v_x in the $x -$ direction and n stands for the number density of that group of of molecules. The total pressure is obtained by summing over the contribution due to all grops:

$$P_{total} = \text{number of molecules} \times \text{mass of one molecule} \times \left(\frac{v_{x1}^2 + v_{x2}^2 + v_{x3}^2}{N}\right)$$

$$= nm\overline{v_x^2}$$

where n is the number of molecules (regardless of their speed) per unit volume and $\overline{v_x^2}$ is the average of v_x^2. There is no preferred direction of velocity of the molecules in the vessel ie. the gas is isotropic. Therefore, by symmetery

- $\overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2} = \frac{1}{3}\left(\overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2}\right) = \frac{1}{3}\overline{v^2}$

wher V is the speed and $\overline{V^2}$ denotes the ***mean of the squared speed***. Thus

$$P_{total} = \frac{1}{3} nm\overline{v^2}$$
$$= \frac{F}{L^2} = \frac{m}{L^3}\left(v_{x1}^2 + v_{x2}^2 + v_{x3}^2 + K + v_{xn}^2\right)$$
$$= \frac{1}{3}\rho \overline{v^2}, \qquad \text{where } \rho \text{ is the density of the gas.}$$

Example 1. Calculate the root mean square speed (v_{rms}) of hydrogen molecule at $0°C$ and atmospheric pressure assuming hydrogen to be an ideal gas. Density of hydrogen at $0°C$ is $9 \times 10^{-2}\,kg/m^3$

Solution:

The root mean square speed from the above equqtion is

$$\bar{v} = \sqrt{\frac{3 \times 1atm}{9 \times 10^{-2} kg/m^3}}$$

But 1 atm = 1.013 x 10^5 Nm^{-2}

$$\therefore \bar{v} = \sqrt{\frac{3 \times 1.031 \times 10^5}{9 \times 10^{-2}}} = 1.85 \times 10^3\,ms^{-1}$$

Kinetic Interpretation of Temperature

The equation

$$P_{total} = \frac{1}{3} nm\overline{v^2}$$

can be written as

$$PV = \frac{2}{3}\left(N \times \frac{1}{2} m\overline{v^2}\right)$$

The quantity in the bracket is the total translational kinetic energy of the molecules in the gas. Since the internal energy E of an ideal gas is purely kinetic

$$E = N \times \frac{1}{2} m\overline{v^2}$$ Therefore,

$$PV = \frac{2}{3}\left(N \times \frac{1}{2} m\overline{v^2} \right)$$

$$= \frac{2}{3} E$$

Combining the above equation with the ideal gas equation we can arrive at the kintic interpratation of temperature:

$$E = \frac{3}{2} k_B NT$$

or

$$\frac{E}{N} = \frac{1}{2} m\overline{v^2} = \frac{3}{2} k_B T$$

This is a fundamental result relating temperature, a macroscopic measurable parameter of a gas to molecular quantity namely the average kinetic energy of molecule.

Internal Energy of a Gas

Average translational kinetic energy of molecules in a gas is related to temperature:

$$K_{avg} = \left(\frac{3}{2}\right) kT$$

The internal energy of a gas is also related just to temperature (not to pressure, or volume). For a monoatomic, ideal gas,

$$E_{int} = nNAKE_{avg} = \left(\frac{3}{2}\right) nRT$$

Thus, the internal energy of all states n an isotherm curve have the same internal energy.

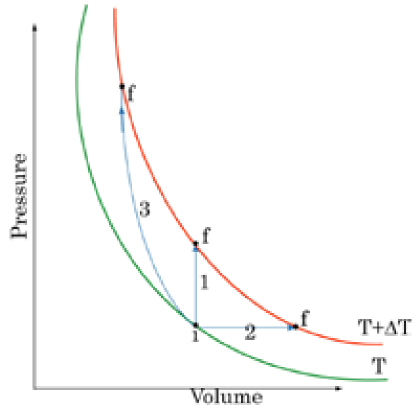

Figure 22
Isotherm curve represent all states having the same internal energy

Specific Heat Constants

Learning Activities

*Reading assignments, Worked Examples, groupworks, experiments, hands on experiences…..

Task 4.1. Kinetic Theory of Gases

Refer to the books listed in the reference section and other references if available to write on the derivation of quantities like temperature from kinetic considerations of molecules.

Task 4.2.Discussion Question

Can Boltzman's constant be regarded as one of the constants of nature? Why?

Formative Evaluation 3

1. All the possible states of an ideal gas can be represented by a PVT surface as illustrated below.

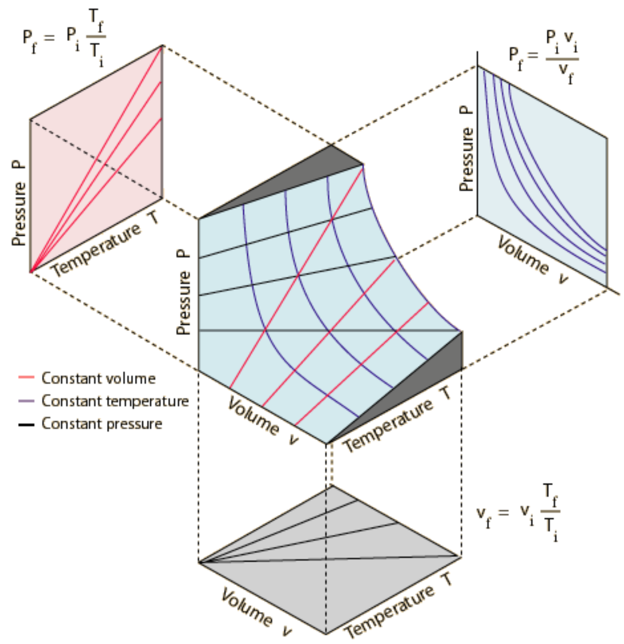

Figure 23
Showing the behaviour of an ideal gas using PVT surface when one of the three variable is held constant.

2. Is it possible to derive laws of a real and volume expansion from the kinetic theory? Discuss
3. What is the rms velocity of water vapor molecules at room temperature?
4. What is the rms velocity of water vapor molecules at freezing temperatures?
5. How many city blocks would a water vapor molecule travel at that velocity, in 1 second?

Activity 5: Heat Engines

You will require 32 hours to complete this activity. In this activity you are guided with a series of readings, Multimedia clips, worked examples and self assessment questions and problems. You are strongly advised to go through the activities and consult all the compulsory materials and use as many as possible useful links and references.

Specific Teaching and Learning Objectives

- State and apply the Second Law of thermodynamics
- Describe Explain what is meant by entropy
- Evaluate various energy cycles (e.g. Carnot cycle, Stirling engine, Refrigeration)

Summary of The Learning Activity

Heat engines, as their name suggests, use heat to generate power. Heat must flow both into and out of a heat engine. Although typically associated with fossil fuels, heat engines (particularly steam turbines) can be powered by renewable energy sources. Solar thermal energy can boil water by using solar energy from the sun. Geothermal energy is utilized by releasing high pressure, high temperature water at the Earth's surface. Upon reaching the surface this water instantly turns to steam. In any case, the steam can be used to power a steam turbine.

Although heat engines have not changed significantly in recent years, it is important to understand how they work in order to design more energy efficient and environmentally friendly engines.

Key Concepts

Heat Engine: Is a device that converts thermal energy into other forms of energy such as mechanical, electrical, etc. Heat engines are cyclic devices.

a. Heat is absorbed from a high temperature reservoir
b. Work is done by the engine
c. Heat is expelled by the engine to a lower temperature reservoir
d. The engine returns to its initial state

Heat engines employ some working substance that is carried through a cyclic thermodynamic process in which the working substance is eventually returned to its initial state. The working substance is most often a fluid or a gas...

List of Relevant Readings for all activities

Reference:- Kittel C. and Kroemer H., (1980) Thermal Physics, 2nd ed., W. H. Freeman and Co., San Francisco, CA..

Abstract:

Rationale: This classic reference on thermal physics is recommended for a serious student of physics. The contents have been treated in detail with adequate mathematical support.

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Abstract:

Rationale: This reading provides easy sources of information. The contents have been treated in lucid manner with adequate mathematical support.

List of Relevant Resources

Reference http://jersey.uoregon.edu/vlab/Piston/index.html

Date Consulted:-Nov 2006

Description:- This Java applet helps you to do a series of virtual experiments, you will control the action of a piston in a pressure chamber which is filled with an ideal gas. The gas is defined by four states: Temperature; Volume or density; Pressure and Molecular Weight

Reference:-: http://lectureonline.cl.msu.edu/~mmp/kap10/cd283.htm.

Date Consulted:- August 2006

Description:- This Java applet helps you understand the effect of temperature and volume on the number of collisions of the gas molecules with the walls. In the applet, you can change the temperature and volume with the sliders on the left side. You can also adjust the time for which the simulation runs. The applet counts all collisions and displays the result after the run. By varying temperature and volume and keeping track of the number of collisions, you can get a good feeling of what the main result of kinetic theory will be.

Reference: video.google.com

Date Consulted: Nov 2006

Complete Reference:- Computer calculation of Phase Diagrams. http://video.google.com/videoplay?docid=1397988176780135580&q=Thermodynamics&hl=en

Rationale: Thermodynamic models of solutions can be used together with data to calculate phase diagrams. These diagrams reveal, for a given set of all parameters (such as temperature, pressure, magnetic field), the phases which are thermodynamically stable and in equilibrium, their volume fractions and their chemical compositions...

List of Relevant Useful Links

Title: Heat Engines

URL: http://en.wikipedia.org/wiki/Heat_engines

Abstract:- The article in wikipedia presents an overview of heat engines, everyday examples, examples of heat engines, efficiency of heat engines etc. A good number of external links are also provided

Title: Heat Engines and Refrigerators

URL: http://theory.phy.umist.ac.uk/~judith/stat_therm/node15.html

Abstract: In any heat engine, heat is extracted from a hot source (eg hot combustion products in a car engine). The engine does work on its surroundings and waste heat is rejected to a cool reservoir (such as the outside air). It is an experimental fact that the waste heat cannot be eliminated, however desirable that might be. Indeed in practical engines, more of the energy extracted from the hot source is wasted than is converted into work. This web page presents a good comparison of different web pages.

Title: Second law of thermodynamics

URL: http://en.wikipedia.org/wiki/Second_law_of_thermodynamics

Abstract:

Title: Second law of thermodynamics

URL: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/seclaw.html

Abstract: The second law of thermodynamics is a general principle which places constraints upon the direction of heat transfer and the attainable efficiencies of heat engines. In so doing, it goes beyond the limitations imposed by the first law of thermodynamics. This webpage presents a visualization in terms of the waterfall analogy.

Introduction to the Activity

Interest in the transfer and transformation of heat energy dates back to the fire age. The study of thermodynamics is developed with the development of heat engines, which is the theme of this activity.

Detailed Description of the Activity (Main Theoretical Elements)

Heat Engines and The Second Law of Thermodynamics

Thermodynamic Cycles

A thermodynamic cycle is a series of processes which change the volume, temperature and pressure of a gas, but which at the end return to the same conditions as at the start. Thermodynamic cycles are important because if we can find one that does something useful for us, it can be repeated indefinitely. Understanding of thermodynamic cycles was extremely important to the industrial revolution and they remain key to most large scale manufacturing processes, to most engines, refrigerators and air conditioners.

Heat engines and refrigerators

The basic principles which enable heat engines and refrigerators to work are as follows:

- (Heat engine) If you allow a gas to expand by moving a piston, then the gas does work on the piston. In this way the kinetic energy in the gas is converted into useful work (moving the piston). When the gas expands, it cools down so at the end of the expansion, we have to heat the gas up again. This is achieved by burning some kind of fuel, e.g. gasoline, coal, nuclear fuel, hydrogen etc.
- (Refrigerator or heat pump) If you want to take heat from a house and pump it outside, you have to take heat from a colder region and move it to a hotter region. This is achieved by using evaporation of a “coolant" liquid. Evaporation of the coolant requires energy (latent heat of vaporization) and this energy is taken from the inside of the object (or rooms) which we want to cool. Once the coolant has evaporated, it is pumped to the compressor, which liquefies the coolant again to complete the cycle. In a refrigerator, the compressor is inside the house, while for an air conditioner, the compressor is outside the house.

In designing a heat engine or heat pump many decisions have to be made, e.g. what is the fuel?, what is the working gas?, what is the nature of the thermodynamic cycle?. Heat engines, such as electrical generators and gasoline engines, use an expanding gas to drive a piston or turbine. In a gasoline engine the expanding gas is a mixture of the products of burning air and gasoline. In a turbine steam is usually used. In a refrigerator or air conditioner evaporation of a coolant gas is used (e.g. Freon, Ammonia, FR-12 etc.).

Heat engines work on a cycle where an incoming gas at low temperature is heated to a higher temperature causing expansion of the gas, which in turn does the mechanical work on the piston or turbine. At the end of the expansion, the working gas still has some heat which is typically lost as waste heat. We define the heat which is added to the gas to cause expansion to be $|Q_h|$, while the heat lost is $|Q_c|$. The efficiency of the engine is defined to be,

$$e = \frac{W}{|Q_h|}$$

Since the working gas at the end of the cycle is at the same temperature as that at which it started, the internal energy is the same at the beginning and at the end. The work done by the engine is then $W_{engine} = |Q_h| - |Q_c|$, so the efficiency of the heat engine is given by,

$$e = \frac{W}{|Q_h|} = \frac{|Q_h| - |Q_c|}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|}$$

The efficiency is in the range $0 \le e \le 1$. E.g. for gasoline engines typical efficiencies are of order 0.25 or 25 percent. A refrigerator is a heat engine in reverse, so that work is done to extract heat from a cold reservoir. This is achieved by evaporating a gas, which extracts heat from its surroundings. For a refrigerator or air conditioner, the coefficient of performance is

$$COP = \frac{|Q_c|}{W}$$

The COP can be greater than one, e.g. 3 is a typical number for a house air conditioner.

The Carnot cycle produces the most efficient heat engine possible. The four steps in a Carnot cycle are: Isothermal expansion; Adiabatic expansion; Isothermal compression; Adiabatic compression. For the Carnot cycle, the efficiency is given by:

$$e_C = 1 - \frac{|Q_c|}{|Q_h|} = 1 - \frac{T_c}{T_h}$$

It is quite hard to prove that the Carnot cycle is the most efficient cycle possible. By reversing the cycle, the Carnot cycle can act as a refrigerator or air conditioner, and in that case, the Carnot coefficient of performance is given by,

$$COP_C = \frac{|Q_c|}{|Q_h| - |Q_c|} = \frac{T_c}{T_h - T_c}$$

Entropy

Entropy is a very important concept in thermodynamics and is also important in philosophical and religious discussions about whether life could possibly have originated spontaneously on our planet.

Entropy is a measure of the amount of disorder in a system. If a system has a lot of different possible configurations, it has high entropy. For example if 100 particles of an ideal gas move randomly in a volume V, then the gas has entropy S. If the same 100 particles are given the same kinetic energy and are placed in volume 2V, then the gas in the larger volume has higher entropy because it has a much larger number of possible configurations.

Boltzmann introduced a quantity Ω , which is the total number of "states" which are available to the gas. It is evident that if the kinetic energy of a gas is fixed, then $\Omega(V, T) < \Omega(2V, T)$. In fact, Boltzmann was able to prove a general relation, that the entropy is given by,

$$S = k_B \ln(\Omega)$$

where S is the entropy, k_B is Boltzmann's constant and is the number of states available to the system. The second law of thermodynamics: In an isolated system, the entropy either stays the same or it increases.

The second law means that in an isolated system the disorder can either stay the same or increase. If we consider that our universe is an isolated system, then the amount of order in our universe can only decrease or stay the same. So how can life, which is very ordered, arise? The key issue is that parts of our universe can become more ordered provided other parts become more disordered, provided that the net effect does not violate the second law. Note also that disorder does not imply high temperatures. Gas particles in interstellar space (which is at $2\sim3K$) have very high entropy because they have a lot of volume to move in.

When does entropy stay the same? An important observation is that when heat is added to a system at fixed temperature, the system must expand. This expansion leads to an increase in volume and hence an increase in entropy. In fact the increase in entropy of an equilibrium process at temperature is given by,

$$\Delta S = \frac{Q_{rev}}{T} \qquad \text{(equilibrium process)}$$

Equilibrium processes are also called reversible processes. The discussion of thermodynamic cycles given above is all based on the assumption of equilibrium. If equilibrium does not occur, then the efficiency is reduced further.

An example of a non-equilibrium process is the free expansion of a gas in a thermodynamically isolated system. This is called an adiabatic expansion as no heat enters or leaves the gas. In this system, the gas particles have the same kinetic energy before and after the expansion. Therefore the temperature is the same before and after. Since no work is done and no heat is added, the internal energy does not change. However the entropy is larger due to the larger volume. This is an example of a process in which $\Delta S > 0$ and is used as an simple example of an expanding universe. Of course our universe is influenced by a gravitational potential which needs to be considered in a complete discussion.

Task 5.1. Essay on different types of engines

Write a historic account of the various heat engines developed in history.

Task 5.2.Entropy in living systems

Discuss the importance of entropy in living systems (highly organized systems)

Formative Evaluation 5

1. Three ideal Carnot engines operate between (a) 400K and 500K, (b) 500K and 600K, and (c) 400K and 600K.
   a. Rank them according to their efficiencies, greatest first.
   b. If they all extract the same amount of energy per cycle from the high temperature reservoir, rank them according to the work per cycle done by the engines, greatest first

2. You can change a refrigerator's coefficient of performance by:
   a. running the cold chamber at a slightly higher temperature;
   b. running the cold chamber at a lower temperature;
   c. moving the unit to a slightly warmer room;
   d. moving the unit to a slightly cooler room.

Optional Formative Evaluation 3

Teaching the Content in Secondary School 3

A good reference is available for high school teaching of the concepts presented in the module:

Saskatchewan Education. (1992).

Science: A Curriculum Guide for the Secondary Level Physics 20/30
Regina, SK:
Saskatchewan Education.
The url is : http://www.sasked.gov.sk.ca/docs/physics/

XV. Summative Evaluation

Long answer questions

1. A glass of water is stirred and then allowed to stand until the water stops moving. What has happened to the kinetic energy of the moving water?
   a. The kinetic energy of the moving water becomes dissipated into internal energy, and the water therefore has a higher temperature than before it was stirred.

2. Why do you think that the heat of vaporization for water is so much larger than the heat of fusion?.
   a. Heat of vaporization includes the energy required to dismantle the energy that hold the water molecule together and to lift them out of the container with very high kinetic energy. The heat of fusion is the energy required to disintegrate the energy that holds molecules at one point. Therefore heat of vaporization is far higher that heat of fusion.

3. A metal pendulum is attached to a clock. The clock keeps correct time at $20°C$. Explain the reading of the clock at $40°C$
   a. The clock loses time. This is because expansion with the rise in temperature, of the size of the pendulum

4. Whenever a system is made to complete a cyclic process, the work done during the complete cycle depends upon the path followed. Explain
   a. Work done is equal to the area of the enclosed figure in P-V diagram. Therefore the work done can not be always zero as in the case of conservative forces.

5. The final temperature t' obtained by mixing $10g$ of the ice at $0°C$ and of water at $10°C$ will not be half way between 10 and 0. Explain.
   a. Upon mixing the two equal masses, the hotter will give off heat and the colder will receive some amount of heat. But in this case the heat received by the colder mass will not go into rising the temperature as it has to be spent on melting the ice. In fact in this case the whole of hot water is cooled down, it does not give enough heat energy to convert whole ice into water.

Multiple Choice questions

1. There are two thermometers based on different thermometric properties of two different materials. The two thermometers show identical readings because
   a. each property changes uniformly with temperature.
   b. the relation between the property and temperature is identical in the two cases
   c. the property of one of increases with temperature and the property of the other decreases at a uniform rate
   d. the two thermometers have been calibrated with reference to a common standard.

2. The gas thermometer is taken as the primary standard because
   a. the thermometers are easily reproducible
   b. readings can be accurately taken
   c. no corrections are necessary
   d. it reproduces the thermodynamic scale.

3. In a Carnot cycle
   a. work done during adiabatic expansion is less than work done during adiabatic compression
   b. work done by working substance during adiabatic expansion is greater than work done during adiabatic compression.
   c. work done during adiabatic expansion is equal to work done during adiabatic compression
   d. work done during adiabatic expansion is equal to the heat absorbed from the source.

4. Which statement is wrong about an ideal gas
   a. the total number of molecules is large
   b. the molecules are in random motion
   c. the molecules do not exert any appreciable force on one another or on the walls
   d. the volume of the molecule is negligibly small compared with the volume occupied by the gas.

5. Mean free path in a gas is
   a. the distance travelled by a molecule before hitting a wall
   b. the average distance travelled by a molecule in one second
   c. the root mean square velocity
   d. the average distance travelled by molecules between any two successive collisions

6. The average molecular kinetic energy at a temperature $T\,°K$ is

a. $\frac{1}{3}KT$

b. $\frac{3}{2}KT$

c. $\frac{1}{2}KT$

d. $\frac{2}{3}KT$

7. The volume of a gas is held constant while its temperature is raised. The pressure the gas exerts on the walls of its container increases because

a. each molecule loses more kinetic energy when it strikes the wall
b. the masses of the molecules increases
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

8. The temperature at which oxygen molecules will have the same root mean square velocity as that of hydrogen molecules at $100°C$ is

a. 3040°C
b. 2768°C
c. 2500°C
d. 2495°C

9. If the RMS velocity of a gas molecule at $-27°C$ is 400m/sec, the RMS velocity at $727°C$ will be

a. 200m/sec
b. 800m/sec
c. 1600m/sec
d. 4000m/sec

10. In practic a disel engine can have greater operating efficiency because:
    a. the efficiency of the Otto engine decreases after a ceratin compression ratio
    b. for the same compression ratio $\eta_d < \eta_o$
    c. the compression ratio of a diesel engine can be increased to a greater value than for an Otto engine
    d. the presence of the spark plug lowers efficiency.

9.2 Answer Key

Long answer questions

1. The kinetic energy of the moving water becomes dissipated into internal energy, and the water therefore has a higher temperature than before it was stirred.
2. Heat of vaporization includes the energy required to dismantle the energy that hold the water molecule together and to lift them out of the container with very high kinetic energy. The heat of fusion is the energy required to disintegrate the energy that holds molecules at one point. Therefore heat of vaporization is far higher that heat of fusion.
3. The clock loses time. This is because expansion with the rise in temperature, of the size of the pendulum
4. Work done is equal to the area of the enclosed figure in P-V diagram. Therefore the work done can not be always zero as in the case of conservative forces.
5. Upon mixing the two equal masses, the hotter will give off heat and the colder will receive some amount of heat. But in this case the heat received by the colder mass will not go into rising the temperature as it has to be spent on melting the ice. In fact in this case the whole of hot water is cooled down; it does not give enough heat energy to convert whole ice into water.

Multiple Choice questions

1. A
2. D
3. C
4. C
5. D
6. B
7. D
8. D
9. B
10. C

XVI. References

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Breif Biography

The author is the currently the chairperson of the department of physics at Addis Ababa University. He has authored school text books that are in uses all over Ethiopian schools. His teaching experience spans from junior secondary school physics to postgraduate courses at the university level. He also worked as a curriculum development expert and Educational materials development panel head at Addis Ababa Education Bureau.

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