F.Y.B.Sc. : Physics : Term-II

HEAT & THERMODYNAMICS AND ELECTROMAGNETICS

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B. M. LAWARE
V. K. DHAS
Dr. P. S. TAMBADE
Dr. B. G. WAGH

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A Book Of

HEAT & THERMODYNAMICS AND ELECTROMAGNETICS

F.Y.B.Sc. Term-II, Paper-I, Section-II : Heat and Thermodynamics
Paper-II, Section-II : Electromagnetics

As Per New Revised Syllabus With Effect from June 2013

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Preface ...

This book entitled **Heat & Thermodynamics and Electromagnetics** has been designed for the courses in Physics at Second Term at F.Y. B.Sc. The text book contains :

1. Paper I: Section – II : Heat and Thermodynamics
2. Paper II : Section – II : Electromagnetics

The textbook is designed for the students preparing for F.Y. B.Sc. examination of Pune University implemented from June 2013. The purpose of the textbook is to give systematic exposition of revised syllabus covering all the topics.

Beginning with its fundamentals the subject has been developed systematically and logically with the emphasis on the physical explanation supported adequately by mathematical formulation. The clarity and systematic representation will make the book intelligible to a beginner. Solved problems have been inserted at appropriate places to illustrate applications of theoretical principles.

In Heat and Thermodynamics section the content is reframed as per the new syllabus of Pune University.

In this course equation of state, critical constants and Joule-Thomson porous plug experiment is explained in detail in first topic. Second topic deals with basic concepts of thermodynamics. In the third topic, application of thermodynamics is discussed and heat transfer mechanism is explained in fourth topic. The last topic includes principles, construction and working of various thermometers.

In section II, Electromagnetics, revision of Coulomb's law, Gauss's law and it's applications in cylindrical, planar and spherical symmetry is discussed in electrostatic topic. Topic second contains dielectrics and it's application.

Revision of Biot-Savart's law, Ampere's law and Gauss's law for magnetism is discussed and in the last topic magnetic properties of material are explained in detail with their applications.

Authors have done sincere efforts to explain above topics in a simple and lucid language as possible.

Although the book is not voluminous, but everything useful and important information has been added. Authors sincerely feel that the work will adequately meet the needs of F.Y.B.Sc. students for a good and concise book which will stimulate a genuine interest among students in the subject.

Authors sincerely thank Shri. Dineshbhai Furia, Mr. Jignesh Furia, Shri. M. P. Munde and entire staff of Nirali Prakashan especially Mr. Santosh Bare, Mr. Kiran Velankar and Mrs. Prachi Sawant for their constant encouragement in this endeavour.

We are also thankful to marketing staff Mr. Nilesh Deshmukh, Ashok Bodake, Nitin Thorat, Sachin Shinde, Mohsin Shaikh for co-ordinating the matter well in time.

Sufficient care has been taken to avoid misprints, checking solutions and answers of numerical examples. However, authors will most gratefully accept suggestions for improving the book and making it more useful.

AUTHORS

Syllabus ...

TERM - II

PHYSICS PAPER I : SECTION II : HEAT AND THERMODYNAMICS

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1.2 Andrew's Experiment
1.3 Amagat's Experiment
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7. Gauss's Law in Dielectrics
8. Electric Vectors and Relation between them

Chapter 3 : Magnetostatics **(9 Lectures)**

1. Revision of Biot-Savart's Law with examples
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3. Gauss's Law for Magnetism

Chapter 4 : Magnetic Properties of Materials **(9 Lectures)**

1. Magnetic Materials and Bohr Magneton
2. Magnetization (M), Magnetic Intensity (H), Magnetic Induction (B), Magnetic Susceptibility and Permeability
3. Relation between $\vec{B}$, $\vec{M}$ and $\vec{H}$
4. Hysteresis

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PAPER - I : SECTION - II : HEAT AND THERMODYNAMICS

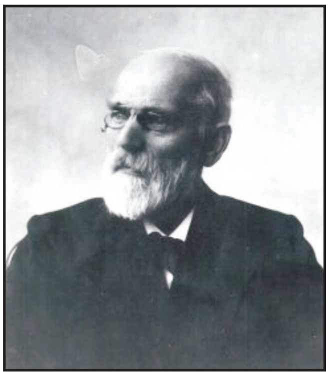
Chapter 1...

Equation of State

Contents ...

J. D. VAN der Waals' was a Dutch scientist and thermodynamicist, famous for his work on **equation of state** for gases and liquids which describe the relationship between the pressure, volume and temperature of fluids.

For his work, he won the 1910 Nobel prize in physics.



Johannes VAN der Waals
(1837-1923)

INTRODUCTION

- To study the behaviour of gases, an ideal gas is used as a model. A gas is termed as an ideal gas or perfect gas if it obeys the gas equation PV = RT rigidly for all values of temperature and pressure. Kinetic theory of gases provides the microscopic description of ideal gas. But if we study the actual behaviour of various gases, no real gas is perfect in this sense. These gases deviate from the ideal behaviour. These real gases tend to show ideal behaviour when the temperature is high and pressure is low. Many modifications to the equation of state of the ideal gas have been suggested to remove these discrepancies. In this chapter, we will study the VAN der Waal's equation of state for real gases.

- In this chapter, we will also study four thermodynamic functions viz. Internal energy, Enthalpy, Gibbs' function and Helmholtz function and their properties.

1.1 Equation of State (April 16, 10)

- Equation of state for any substance is a mathematical formula which expresses the relationship between the volume, pressure and temperature of a substance in any state of aggregation.

  The equation of state for one mole of perfect or ideal gas is

  $$PV = RT \quad \dots (1.1)$$

  In the above equation,

  P is pressure in N/m^2 or $dyne/cm^2$

  R is gas constant and its value is 8.31×10^7 ergs/g mol-K

  T is temperature in °K

  and V is the volume occupied by the gas.

- It should be noted that an equation of state is valid only when the gases are in thermodynamic equilibrium states. No equation of state exists for non-equilibrium states which are traversed by the system since such states cannot be defined in terms of thermodynamic co-ordinates referring the system as a whole.

- The perfect gas equation is PV = RT. For a fixed mass of a gas, if the temperature is kept constant, then we get PV = constant. This is *Boyle's law*. The perfect gas obeys Boyle's law and Charle's law under all conditions of temperature and pressure.

- However, if we study the behaviour of various gases like CO_2, H_2, NO_2, these gases are not perfect in this sense. Such gases are called real gases. These gases obey Boyle's law only when the temperature is high and pressure is low. At high pressures and low temperatures, they show considerable deviation from ideal gas laws. These deviations are maximum in the case of gases which are easily liquified, such as carbon dioxide, ammonia and sulphur dioxide.

- Experiments by Regnault, Amagat and others showed that, over an extended pressure range, no real gas obeys Boyle's law. Hence no gas is perfect if we define a perfect gas which obeys Boyle's law. It is observed that in real gases, for a fixed mass of a gas, the product PV is not constant, but is a function of pressure. The variations of PV with pressure P are shown in Fig. 1.1.

- For every gas there is a certain temperature at which the product PV is independent of P and obeys Boyle's law. This temperature is known as *Boyle's temperature* and it is the characteristic of each gas. Above the Boyle's temperature, the product PV increases with the pressure P. Below the Boyle's temperature, the product PV first decreases with increase in P, it reaches a minimum value and then begins to increase with P.

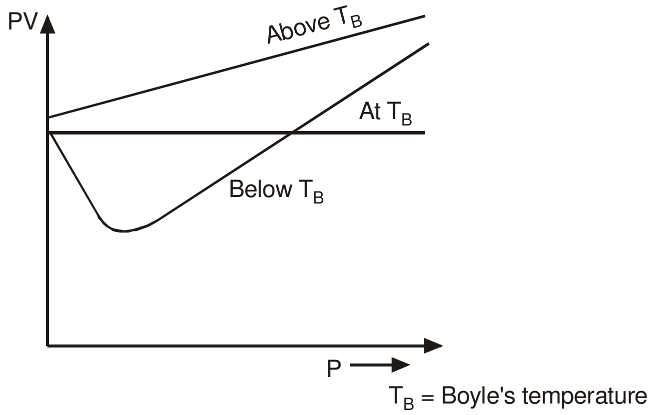


Fig. 1.1 : Typical isotherms of real gases (arbitrary scale)

- It appears that the general nature of the deviation from the Boyle's law depends on the temperature and not on the nature of the gas. It is observed that real gases obey Boyle's law generally at very low pressure and moderately high pressure.
- Based on the experimental results of Andrews, Amagat and others, Kammerlingh Onnes suggested an empirical equation

$$PV = A + BP + CP^2 + DP^3 + \ldots \qquad \ldots (1.2)$$

where A, B, C, D, ... are called *virial coefficients*. These constants depend on the nature of the gas and change with the temperature of the gas. The coefficient B is of great importance for real gases. Because for real gases B varies with temperature in similar manner. At low temperature its value is negative and increases through zero to positive values at higher temperatures. The temperature at which the value of B is zero is called Boyle temperature. Also C, D,.... are negligible at this temperature and therefore from equation (1.2), we get

$$PV = A = \text{constant.}$$

and
$$B = \frac{d(PV)}{dP} = 0$$

- The nature of graph in Fig. 1.1 shows that below the Boyle's temperature, the gases are highly compressible and this suggests that the molecular interactions exist between the molecules. Above the Boyle's temperature, Boyle's law is obeyed and intermolecular attractions are less significant.

1.2 Andrews' Experiment (April 17; Oct. 16, 10)

- In 1869, Thomas Andrews performed experiments on CO_2 to study the relationship between pressure and volume of the gas at various constant temperatures. He plotted isothermal curves between pressure and volume at different constant temperatures.
- The apparatus used by Andrews to study the isothermals of CO_2 at various temperatures are shown in Fig. 1.2.

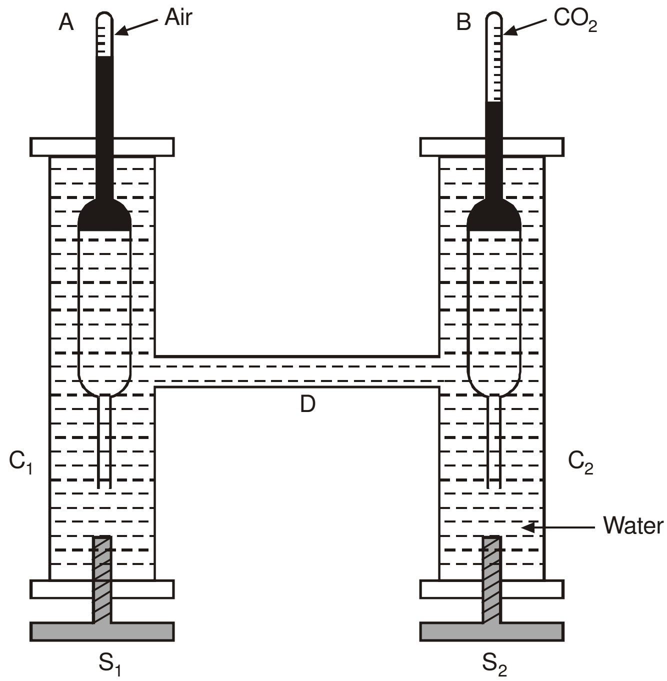


Fig. 1.2 : Andrews' apparatus

- A and B are two similar hard glass tubes having thick capillary tubes at the top and bulbs in the middle. The capillary tubes in the top of tubes A and B are graduated to read volume directly. Initially both the ends of each tube are open. In tube A, pure dry air is passed for a long time and it is sealed. In tube B, carbon dioxide is passed for long time (about 24 hours) and the ends are sealed. The lower ends of both the tubes are then immersed in mercury and they are then reopened under mercury.
- A small pellet of mercury is drawn in both the tubes by alternately heating and cooling the tubes. These mercury pellets act as movable stoppers. Both the tubes A and B are mounted in a H-shaped copper vessel as shown in Fig. 1.2.
- The copper vessel is filled with water. The screw plungers S_1 and S_2 are fitted at the bottom of H-vessel as shown in Fig. 1.2. With the help of these plungers, pressure can be applied on the gas and the air. The capillary portions of the tubes A and B are kept surrounded by constant temperature baths.