Vacuum Technology

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Preface

Developments in the vacuum field have been rapid during the last few years. These developments have included much larger systems, new techniques and equipment, and operation at extremely low pressures. More people are continually becoming involved in vacuum work. There are a number of excellent books on the subject of vacuum; however, in general, they assume a fair degree of scientific knowledge on the part of the reader and treat the broader principles and techniques of vacuum. It is the purpose of this book to consolidate the vast amount of material on this subject, both published and unpublished, into sets of working rules primarily for technicians engaged in setting up, operating, and maintaining vacuum systems.

The treatment is nonmathematical, with the arithmetic used extending only to the application of decimals, powers of ten, and logarithms. Where simple arithmetic is involved, numerous examples are given. However, tables, graphs, and simple rules are employed extensively. Using the material in this book, the technician should be able to choose the appropriate commercial vacuum components, fabricate various parts for vacuum use, set up a complete system, test components and complete systems, perform routine maintenance, and recognize and correct malfunctions. Chapter 14 is devoted exclusively to very high and ultra-high vacuum systems, but some information pertaining to such systems is contained in other chapters.

Although this book is intended primarily for the technician, it is hoped that it will be useful to a certain degree to the engineer and the scientist because of its tables and graphs, and the physical data and design formulas included in the appendices.

The terminology used generally follows that recommended by the American Vacuum Society in its *Glossary of Terms Used in Vacuum Technology* (Pergamon Press, London, 1958). Extensive use has been made of data from various manufacturers, and every effort has been made to acknowledge the source of such information in the text.

I wish to express my appreciation to Carole Abbott for typing the manuscript, and for subsequent help on details which had to be worked out while the book was in various stages of publication.

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ONE

The Nature of Vacuum

1.1 What Is Vacuum?

The word vacuum is derived from the Greek word meaning empty. In practice some type of vessel (vacuum enclosure, chamber, or container) which is open to the surrounding air is used. As air is removed by some pumping means, a vacuum is obtained. Clearly various degrees of vacuum can be obtained, depending on how much air is removed from the enclosure. Practically, a vacuum vessel which is empty, i.e., free of all matter, is never obtained. If this were possible the vacuum would be called *perfect* or *absolute*. Many vacuum terms are defined in the text as they are used. The subject of vacuum is treated in general in the references listed in Appendix E.

1.2 General Nature of a Gas

The word gas is often used loosely in vacuum practice to denote both *noncondensable* gases and *vapors*. The noncondensable gases, sometimes called *permanent* gases, cannot be compressed to liquid or solid form at ordinary room temperature. Dry air is an example of a noncondensable gas, and water vapor is an example of a vapor.

In order to produce liquid air it is necessary not only to use a high degree of compression but also to do so at low temperatures.

A gas is made up of many, small, invisible particles called molecules which are moving about rapidly in all directions. It is possible to visualize these molecules by imagining tennis balls moving about rapidly in all directions in a room. They collide with each other and rebound from the walls of the room. Most of them move with about the same speed, although occasionally it will be observed that one moves considerably faster or slower than the others. Figure 1.1 is a schematic representation of a vessel containing a gas. The arrows show the directions in which the molecules are moving, and it is found that, on the average, as many molecules are moving in one direction as in any other direction.

If the enclosure shown in Fig. 1.1 were heated, it would be found that the molecules had a greater mean speed than before the enclosure was heated. Again an occasional molecule would be found to be moving considerably faster or slower than the bulk of the molecules. The speeds of molecules are quite high, even at room temperature (20° centigrade or 68° Fahrenheit). At this temperature a hydrogen molecule has an average speed of about 5700 feet per second whereas an air molecule has an average speed of about 1500 feet per second. Actually air consists of several gases, the most prominent being nitrogen and oxygen (see Table 1.1). The average speed for an air molecule given above is an average for the molecules of the various gaseous constituents. The distance between molecules is, on the average, much greater than the diameter of a molecule. This is true for the air

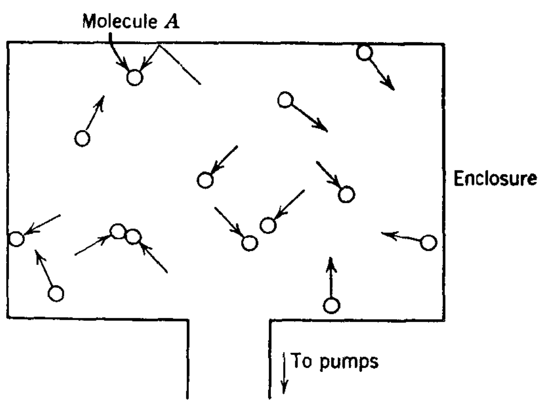

Fig. 1.1 Molecules moving about in an enclosure.

Table 1.1 Composition of Dry Air at Sea Level

Gas	Percent by Volume
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Carbon dioxide	0.03
Neon	0.0018
Helium	0.0005
Methane	0.0002
Krypton	0.0001
Hydrogen	0.00005
Xenon, etc.	Traces

Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, Ohio, 43rd ed., 1961.

around us, and if some of the air is removed from such an enclosure as shown in Fig. 1.1, the average distance increases since there are fewer molecules distributed through the volume.

Referring again to Fig. 1.1, it is seen that molecule *A* has struck the inside wall of the enclosure and rebounded. Actually many molecules strike the wall in a short time, and they strike from all directions up to grazing incidence. The striking and rebounding of the molecule results in a "push" or force on the wall. The average force on a unit area of the wall, say one square inch, is called the *pressure.* This is a fundamental quantity in vacuum work. The pressure of a gas depends on how many molecules are striking the unit area in any given time (a second, a minute, etc.) and on how fast they are moving. Consequently, the pressure will drop as the gas is pumped out (fewer molecules) and will rise as the gas is heated (molecules move faster).

It has been stated that a gas exerts a pressure on the inside walls of the enclosure. Actually there is a gas pressure anywhere in the gas. Suppose an object, such as a sheet of metal, is placed in the enclosure. Then each side of the sheet will be subjected to a pressure equal to that exerted on the inside walls of the enclosure. This is illustrated in Fig. 1.2. Although many units of pressure are used in

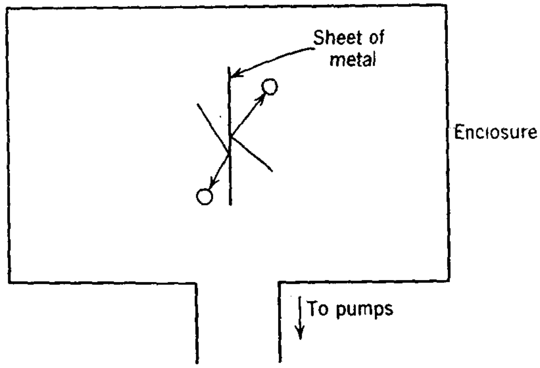

Fig. 1.2 Molecules exert a pressure on an object in the gas.

practice, they are all derived from one basic unit, which depends on the characteristics of the air around us (the atmosphere). Consequently, this unit is discussed next.

1.3 The Atmosphere

Since in most vacuum work some type of vessel which is open to the air (the atmosphere) is used, gases making up the atmosphere are of considerable importance. Table 1.1 shows the proportions of the various gases making up dry air at sea level. The proportions change (very slowly) with altitude, but this change becomes significant only at extremely high altitudes.

The atmosphere exerts a pressure on any object immersed in it. Normally reference is made to the pressure at sea level and at a temperature of 0° centigrade (0°C) or 32° Fahrenheit (32°F), called the *standard* or *normal atmosphere* (atm). The relationships between the various temperature scales are discussed in Section 1.8. To measure the actual pressure of the atmosphere, a glass U-tube partially filled with mercury is used, with one end connected to some type of vacuum pump. This is illustrated in Fig. 1.3*b*. If both ends of the U-tube are exposed to air, the mercury levels in both sides will be the same (Fig. 1.3*a*). This is simply an example of a liquid seeking its own level. If one side of the U-tube is connected to the vacuum pump, the mercury will rise in that side and fall in the other side, as is shown in Fig. 1.3*b*. This difference in level is caused by the atmosphere exerting a pressure on the mercury in side *B*. There is no balancing pressure on side *A*

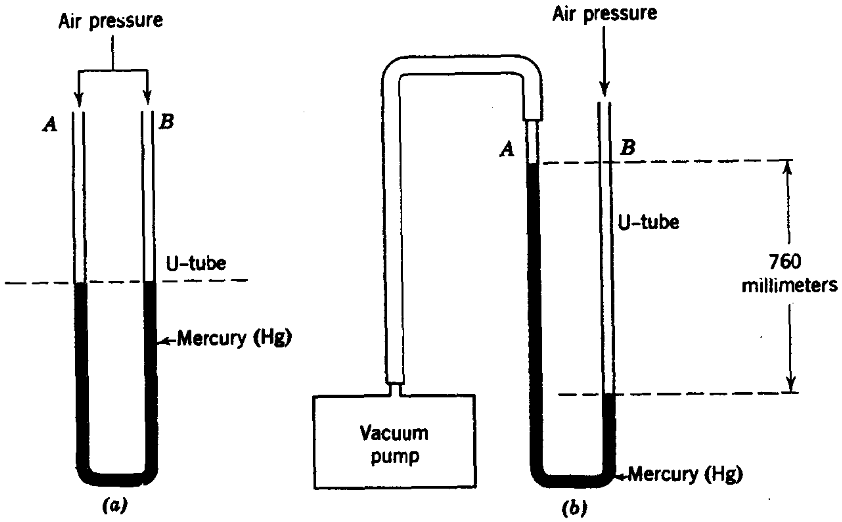

Fig. 1.3 (*a*) U-tube with both sides exposed to the atmosphere. (*b*) U-tube with one side pumped.

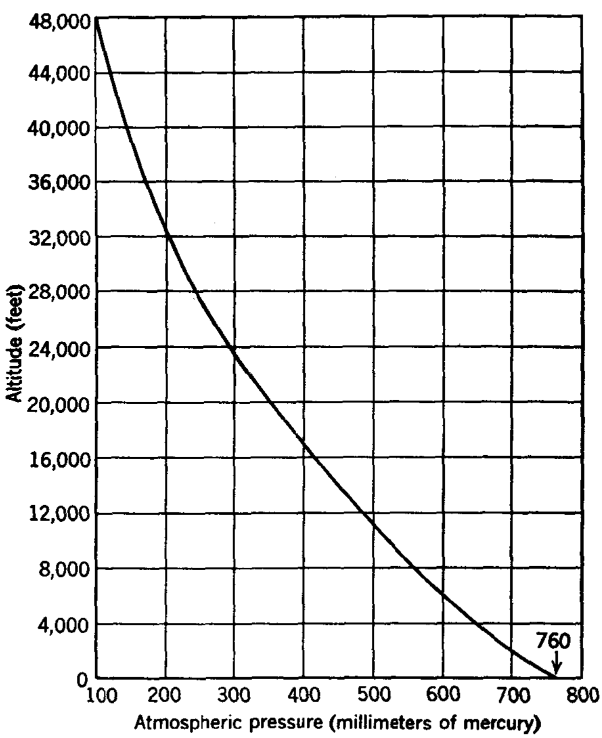

Fig. 1.4 Change in atmospheric pressure with altitude.