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WAR DEPARTMENT

TECHNICAL MANUAL

AEROSTATICS

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AEROSTATICS

Prepared under direction of the Chief of the Air Corps

SECTION I

GENERAL

1. Scope.—*a.* This manual treats the factors involved in the study of aerostatics as applied to airships and balloons. Each factor

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will be analyzed separately, then all collectively so that their cause and effect can be thoroughly understood. In order to facilitate advance of the beginner, successive factors will be treated in an elementary way, leading up step by step to complete development of the formulas and to the harder problems.

b. The subject matter has been so arranged that this manual is at the same time a text for the student and a reference book for the airship pilot or designer, covering briefly the most important aerostatic problems with which they may be confronted.

2. Definition of aerostatics.—Aerostatics treats of the gravitational factors which affect the equilibrium of a body which is freely in suspension in the atmosphere.

3. Types of lighter-than-air aircraft.—*a*. There are in reality three different types of lighter-than-air aircraft and special aerostatic considerations are required for each type. They are as follows:

(1) The free balloon.

(2) The captive balloon.

(3) The airship or dirigible balloon.

b. The balloon and airship are distinctly lighter-than-air machines filled with a gas which is lighter than air, such as hydrogen or helium, which by displacement of an equal volume of air gives a buoyancy or flotation the magnitude of which is determined by the volume of the gas container, the kind and purity of the gas, the atmospheric conditions, etc. When the term "free balloon" is used it means that the balloon is floating freely in the atmosphere with only static means of control. Then the piloting of a free balloon resolves into the study of the static forces affecting the equilibrium of a balloon freely suspended in the atmosphere and the practical methods of weighing the balloon (at each instant) in order to keep the forces of buoyance and weight correctly related at all times. This is accomplished by the proper expenditure of ballast (which is a part of the load used for ballooning purposes) and a judicious use of the valve for the expenditure of gas when desired. The dirigible balloon or airship is a balloon of streamline shape, equipped with propelling mechanism and steering apparatus.

4. Differences in construction that must be taken into consideration in aerostatic problems.—*a*. Airships are constructed in three different types as follows:

(1) Nonrigid.

(2) Semirigid.

(3) Rigid.

b. These type designations refer entirely to the construction and the combination of the gas container and framework supporting the weight of the craft and its load. There are special considerations for each type of airship in aerostatics due to differences in their construction. In the nonrigid and semirigid the ballonets and their capacity must be considered, whereas this is not the case in rigid airships in which ballonets are not used.

c. To assist those who may not be familiar with the construction of the different types of lighter-than-air aircraft to a clearer understanding of the expressions and terms used in the text, a brief explanation is given below.

(1) The envelope of a nonrigid or semirigid airship contains one or more small bags inside which are called ballonets. These ballonets are inflated with air by means of the airship propeller or by an auxiliary blower to help maintain a constant internal pressure and volume by which rigidity of shape of the envelope is maintained.

(2) When an airship ascends and as the altitude increases, the atmospheric pressure and density decrease, thereby allowing the gas to expand or to increase the relative internal pressure of the gas. In order to take care of this expansion, air is valved from the air compartments or ballonets, which can be so regulated by the valves as to keep the internal pressure constant during the ascent.

(3) If the airship should leave the ground full of gas there would be no available space in the ballonets for air; therefore, it would be necessary to valve gas during ascent.

(4) Upon descending from any altitude the opposite effect to ascent is experienced; that is, the airship is descending into atmosphere of increasing density which has the effect of compressing the gas and lowering the relative internal pressure. In this case, to maintain a constant internal volume or pressure it becomes necessary to force air into the ballonets.

(5) In small airships having two ballonets where the weight is concentrated in a single car and where shifting weights is not practicable, the airship is trimmed by shifting the air in the ballonets, thereby shifting the center of buoyancy of the envelope. Airships having but one ballonet cannot be trimmed in this manner.

NOTE.—Nonrigid and semirigid airships are sometimes referred to as pressure airships as they must be operated constantly under internal gas pressure. The preceding discussion is applicable to either semirigid or nonrigid types of airships.

(6) In rigid airship construction, as rigidity and shape are maintained by the rigid structure of the framework and not by internal gas pressure, no ballonets or air compartments in the gas cells are used.

This simplicity of gas cell construction greatly simplifies the operation of rigid airships in that there is no necessity for constant attention to pressure when the rigid airship is flying below pressure height.

5. Importance of aerostatics and types of problems involved therein.—*a*. All airship pilots must master thoroughly the subject of aerostatics, and must become so familiar with the relations between the gas and the supporting air that they will know immediately the effect of any change in any of the factors of lift. Accuracy becomes more and more important as size of airships increases and an error, negligible perhaps for a small airship of 250,000 cubic feet capacity, might prove to be disastrous for the airship and its crew in the case of an airship with a volume of 2,500,000 cubic feet or more. The rules developed for the airship of the first-mentioned size prove to be satisfactory for airships of larger volume but must always be used with utmost caution, and when errors are found to exist they must be overcome by quick and intelligent application of the fundamentals treated in this text.

b. A few of the problems of greatest importance are to—

(1) Determine total lift or buoyancy of an airship when—

(*a*) Air and gas temperatures are the same.

(*b*) Air and gas temperatures are not the same (with superheat).

(*c*) There is a change in lift due to changes in the superheat value while in flight.

(2) Determine percentage of fullness (F) when necessary to—

(*a*) Lift a given load.

(*b*) Reach a given altitude without loss of gas.

(3) Determine altitude at which the airship will become full of gas (pressure height) under any set of atmospheric conditions and percentage of fullness.

(4) Determine maximum altitude of airships.

(*a*) Ballonet ceiling (for nonrigids and semirigids).

(*b*) Ballast ceiling (for all types).

c. Study of the foregoing problems requires an understanding of—

(1) Causes effecting changes in gas volume.

(*a*) Temperature effects.

1. Isothermal expansion.

2. Adiabatic expansion.

(*b*) Pressure changes; the changes of pressure with altitude.

(*c*) Superpressure.

(2) Physical properties of gases.

(*a*) Density (D).

(*b*) Specific gravity (S).
(*c*) Purity (Y).
(*d*) Humidity (e).

6. Résumé of symbols.—The following is a résumé of all symbols used in this manual:

a=Coefficient of expansion.
B=Ballonet ratio.
b=Disposable weight.
C_g=Constant (used in determining gas density).
D_a=Density of air.
D_g=Density of gas.
D_o=Density under standard conditions of P and T.
e=Vapor pressure.
F=Percentage of fullness.
G=Glaisher's factor.
H=Homogeneous height.
h=Height in feet.
K=Constant (used in determining the density of air).
L=Gross lift of gas=Gross load.
m=Mean or average.
P=Pressure in inches of mercury.
$P.\ H.$=Pressure height.
S=Specific gravity of gas.
T=Temperature absolute.
T_a=Temperature of air (absolute).
T_g=Temperature of gas (absolute).
t=Temperature recorded by thermometer (not absolute).
U=Static efficiency.
V=Initial volume, but used in the lift formulas to indicate displaced volume of envelope or cells when full of gas.
V'=Actual volume of gas under any given set of conditions.
v=Volume of ballonet.
Y=Purity of gas.
ΔL=A change in lift.
ΔT=Temperature difference (or superheat).
ΔV=A change in volume.

SECTION II

ATMOSPHERE AND PHYSICAL PROPERTIES OF GASES

7. Atmosphere.—*a.* For a complete understanding of the subject of aerostatics which deals with flotation of lighter-than-air aircraft by the buoyancy arising from the differences in weight between the air and the inflating gas used, it is necessary first to make a brief study of the atmosphere which is the sustaining medium.

b. The atmosphere is defined as the gaseous envelope which surrounds the earth. It is composed of a mixture of gases and at mean sea level under average conditions, *excluding water vapor*, consists of approximately—

Nitrogen	78.00
Oxygen	20.95
Argon	.91
Carbon dioxide	.03
Hydrogen	.01
Other gases	.10
Total	100.00

As can be seen from the foregoing, nitrogen and oxygen are the two principal components, hydrogen and other gases being present in very small quantities. At an altitude of about 30,000 feet the amount of hydrogen is about double that at the earth's surface. From this point up to about 50 miles the proportion of hydrogen and helium is supposed to increase until the atmosphere is composed almost entirely of these two elements.

c. The atmosphere is subject to changes in condition, but only in a very small degree to changes in composition near the earth's surface. For purpose of study of aerostatics it is assumed that pressure, temperature, and humidity of the atmosphere alone affect aerostatic computations. Of these three the first two affect only condition of the atmosphere, while the third affects both condition and composition. Any effects of latitude upon gravity will be neglected as they are negligible for practical purposes. The causes which operate to alter pressure, temperature, and composition of the atmosphere are treated in the study of meteorology. These causes can be traced and, to a certain extent, changes in condition of the atmosphere can be foretold. The barometric pressure curve (fig. 1) shows the rapid drop in pressure during ascent up to about 6 miles where the curve changes less rapidly; also that about half of the earth's air, by weight, lies below 20,000 feet, or less than 4 miles. The pressure is reduced by approximately one-half for every 3⅗₀ miles of ascent.

8. Physical properties of gases.—*a.* As it is necessary to use gases for inflation of lighter-than-air aircraft, it is necessary to make a study of some of their physical properties. The ideal balloon would be one containing a vacuum, but due to the tremendous value of the atmospheric pressure it is impossible to build a balloon strong enough to contain a vacuum and yet be light enough to float in the atmosphere. In reality the gas in a balloon (by opposing the external or atmospheric pressure) serves as a medium by which internal pressure or shape is maintained in the balloon or airship envelope.

(1) Both liquids and gases are fluids. A fluid does not offer permanent resistance to forces tending to produce a change of shape, that is, its modulus of shear is very low. The resistance or friction to distortion is called the viscosity of the fluid. The three important differences between gases and liquids are—

(*a*) Gases are compressible.

(*b*) Gases change volume rapidly with changes in temperature.

(*c*) Gas atoms or molecules appear to have the same electrical charges or to possess the property of repelling each other.

(2) *Density.*—The weight of the unit of volume of a body is called the "density" of that body. The density is thus the force of gravity acting on the mass of a unit volume.

$$\text{Density} = \frac{\text{weight of body}}{\text{volume of body}}$$

In the metric system the unit of volume is the cubic meter and the unit of force the kilogram; the density is expressed in kilograms per cubic meter. For water and air the densities are, respectively, 1,000 kilograms per cubic meter and 1.293 kilograms per cubic meter. In the English system of units, the unit of volume being the cubic foot and the unit of force the pound, the density of gas is expressed in pounds per cubic foot. For air under standard conditions the density is 0.08072 pound per cubic foot, or 80.72 pounds per 1,000 cubic feet. In the case of gases conditions of pressure and of temperature are of such importance that it is impossible for them not to be taken into consideration. The gas used for purposes of comparison is air under established conditions of purity. The composition of atmospheric air is remarkably constant, as previously stated, except for the proportion of water vapor it contains. This variability is eliminated by taking dry air as a standard of comparison. In determining the standard densities or specific gravities of air and other gases, the temperature is supposed to be maintained at 0° centigrade (32° F.) and under a constant pressure of 760 millimeters of mercury (29.92 inches). Under these conditions of P and t the standard density of dry air is 1.293 kilograms per cubic meter (0.08072 pound per cubic foot) and is the standard of comparison from which specific gravities of all gases are determined.

(3) *Specific gravity.*—The ratio of the density of a given substance to the density of some substance adopted as a standard, both being subjected to identical conditions of pressure and temperature, is known as the specific gravity of the given substance. This ratio is independent of the system of units employed, but both densities must be expressed in similar units. Dry air is the standard of comparison for determining the specific gravity of gases. The specific gravity of a gas is the ratio between the weight of a unit volume of that gas and the weight of the same volume of dry air taken under the same conditions of temperature and pressure.

$$S_g=\frac{D_g}{D_a}=\frac{\text{weight of unit volume of gas}}{\text{weight of unit volume of air}}.$$

For instance, the densities under standard conditions of dry air and hydrogen are, respectively, 0.0807 and 0.0056 pound. Therefore, the specific gravity of H is

$$S_g=\frac{0.0056}{0.0807}=0.069.$$

The ratio thus obtained is practically constant whatever may be conditions of temperature and pressure. In other words, the coefficients of expansion of all gases are the same.

b. The following are the constant densities and specific gravities for some gases under standard conditions of pressure and temperature:

(1) *Standard density.*—(*a*) Air=0.08072 pound per cubic foot.

(*b*) Hydrogen=0.00562 pound per cubic foot.

(*c*) Helium=0.0111 pound per cubic foot.

(2) *Average density* of illuminating gas=0.0323 pound per cubic foot.

(3) *Specific gravity.*—(*a*) Dry air=1.

(*b*) Pure hydrogen=0.069.

(*c*) Pure helium=0.138.

(4) *Average specific gravity* of illuminating gas=0.4 (approximate).

NOTE.—Gas produced in large quantities as for inflation of balloons cannot be obtained chemically pure in manufacture. Its specific gravity will therefore be higher than the preceding.

9. Laws governing aerostatics.—The science of aerostatics is derived from the following laws and fundamentals:

a. Archimedes's principle.—The buoyant force exerted upon a body immersed in a fluid is equal to the weight of the fluid displaced.

b. Boyle's law.—At constant temperature the volume of a gas varies inversely as the pressure.

c. Charles' law.—At constant pressure the volume of a gas varies directly as the absolute temperature.

d. Dalton's law.—The pressure of a mixture of several gases in a given space is equal to the sum of the pressures, which each gas would exert by itself if confined in that space.

e. Joule's law.—Gases in expanding do no interior work.

f. Pascal's law.—The fluid pressure due to external pressure on the walls of the containing vessel is the same at all points throughout the fluid.

NOTE.—Effects of latitude and altitude upon the force of gravity are neglected in practical operation and will therefore be omitted from this manual.

SECTION III

THEORY OF LIFT OR BUOYANCY

10. Force producing lift or buoyancy.—*a.* The Archimedes's principle states that the buoyant force exerted upon a body immersed in a fluid is equal to the weight of the fluid displaced. When a body is completely submerged in water it displaces a quantity of water equal to its own volume. If the weight of the water displaced is greater than the weight of the body it will rise to the surface of the water, but if the weight of the water is less than the weight of the body submerged the body will sink to the bottom.

b. If a cube is immersed in a vessel filled with water a pressure will be exerted on all of its six faces or sides. This can be represented graphically as shown in figure 2.

(1) There are two vertical forces acting on the cube, one pressing on top and tending to force the cube to the bottom and one force

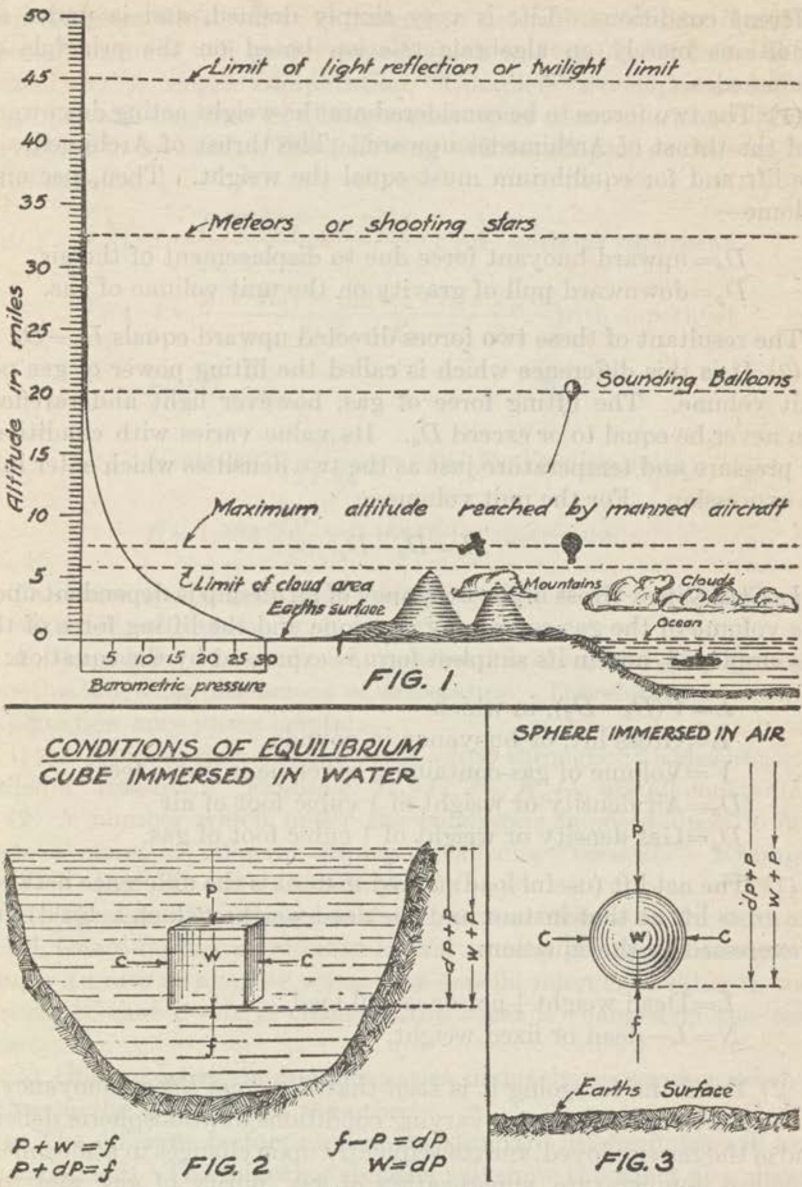
acting vertically against the bottom of the cube and tending to cause it to rise to the surface. There are additional forces acting horizontally against the four sides of the cube which can be regarded as crushing forces only, producing no buoyant effect.

(2) Water pressure is transmitted equally in all directions. Hence the force f directed upward on the lower surface of the cube is equal to the weight of a column of water of the same cross section as the cube and extending from the level of its lower surface to the top of the water. The force P is equal to the weight of a similar column of water extending from the top surface of the cube to the surface of the water. The difference between these two, $f-P$, must equal the weight of a volume of water equal in size to the cube itself. This explains Archimedes's principle, since $f-P$ is the resultant upward force of the water.

(3) If the specific gravity (or density) of the body should be the same as that of water it would be in a state of equilibrium, in which case the force $P+W=f$, f being the total force of the pressure acting upward. The above condition is necessary for equilibrium, for if $P+W$ is greater than f the cube will sink, or if $P+W$ is less than f the cube will rise to the surface of the water.

c. The fundamentals of operation of a submarine and an airship are very similar as both are submerged in a fluid and derive their buoyancy from the weight of the fluid displaced. Their methods of control are almost identical and both use ballast to vary their buoyancy.

(1) If a submarine weighs less than the weight of water equal to its own volume it will float upon the surface of the water, but by pumping water into her ballast tanks she can be brought to a state of equilibrium which is the point at which the weight of the submarine exactly equals the weight of the water displaced. When in equilibrium the submarine can submerge beneath the surface of the water, but it is impossible to admit ballast so accurately as to leave her in a state of stable equilibrium. This difference between the characteristics of a submarine and those of an airship, in that the airship may ride at equilibrium and the submarine cannot float in equilibrium when submerged under ordinary conditions, is due to the difference of air and water characteristics. The density of the water is practically constant while descending or ascending, that is, its density changes very little under changes of pressure and temperature, but the density of the air varies greatly with these changes during ascent or descent. Hence, when a submarine is submerged it is necessary to maintain dynamic means of control at all times to maintain the desired level beneath the surface of the water.



FIGURES 1, 2, and 3.

(2) Figure 3 shows the forces acting upon a sphere filled with gas and floating in the air.

11. Lift or buoyancy of gases.—*a.* The most important subject in airship flights is determination of lift and how it will vary under different conditions. Lift is very simply defined, and is under all conditions merely an algebraic relation based on the principle of Archimedes.

(1) The two forces to be considered are the weight acting downward and the thrust of Archimedes upward. The thrust of Archimedes is the lift and for equilibrium must equal the weight. Then, per unit volume—

D_a=upward buoyant force due to displacement of the air.
D_g=downward pull of gravity on the unit volume of gas.

The resultant of these two forces directed upward equals $D_a - D_g$.

(2) It is this difference which is called the lifting power of gas per unit volume. The lifting force of gas, however light and rarefied, can never be equal to or exceed D_a. Its value varies with conditions of pressure and temperature just as the two densities which enter into its expression. For the unit volume—

$$L = D_a - D_g.$$

b. *Static lift.*—Gross lift or buoyancy of an airship is dependent upon the volume of the gas-containing envelope and the lifting force of the gas employed, and in its simplest form is expressed by the equation:

$L = V(D_a - D_g)$, in which
L=Gross lift, or buoyancy in pounds
V=Volume of gas-containing envelope in cubic feet
D_a=Air density or weight of 1 cubic foot of air
D_g=Gas density or weight of 1 cubic foot of gas.

(1) The net lift (useful load) at any instant is the difference between the gross lift at that instant and the dead weight (which is fixed) and is exoressed by the equation:

L=Dead weight+net or useful load.
$N = L -$dead or fixed weight.

(2) From the foregoing it is seen that the *gross lift* or buoyancy is a variable, depending upon varying conditions of atmospheric density and of the gas employed, and consequently upon changes in atmospheric pressure, temperature, superheating of gas, purity of gas, and to a small degree on humidity of the air.

c. Determination of lift therefore becomes a matter of determining densities of the atmospheric air and the gas used. However, it becomes too cumbersome to be compelled to compute separately the two densities whenever it is desired to determine the lift; therefore, special formulas will be developed which will enable lift to be determined by a single computation. Complete development of lift formulas will be given in a later section after discussing the different variables to be used. The following will be adopted as the standard lift formulas:

$$LF1;\ L=\frac{F\ V\ K(P-0.38e)}{T}\ (1-S)\ \text{without superheat}$$

$$LF2;\ L=\frac{F\ V\ K(P-0.38e)\ (T_g-T_aS)}{T_a\times T_g}\ \text{with superheat}$$

$$K=D_{ao}\frac{T_o}{P_o}$$

$$K=0.08072\,\frac{492°}{29.92''}=1.327 \text{ for English units}$$

$$K=1.293\,\frac{273°}{760}=0.46446 \text{ for metric units.}$$

The subscript ($_o$) used above indicates that D, P, and T are taken at standard conditions.

d. The words "variable" and "constant" will be used often throughout the following discussions of aerostatics. Therefore the following explanation may prove helpful:

(1) A number that has the same value throughout a discussion is called a "*constant.*" Example: P_o, T_o, D_o, K, C_g, are all constants.

(2) A number which under the conditions imposed upon it may have a series of different values is called a "*variable.*" Example: P, T, V, D, S, Y, e are all variables.

(3) The sign of variation is $\propto$. It is read "varies as."

(4) One quantity or number is said to *vary directly* as another or simply to *vary* as another when they depend upon each other in such a manner that if one is changed, the other is changed in the same ratio.

(5) One quantity or number varies inversely as another when it varies as the reciprocal of the other.

e. The different factors used in the standard lift formulas will next be explained. The following sections will show the effect of a change in any one of these variables and how the formulas are developed by treating separately all the variables entering into the computation, then combining them into the standard lift formulas.

Section IV

PRESSURE AND TEMPERATURE

(Variables "*P*" and "*T*")

12. Absolute temperature scale and theory of heat.—*a*. Heat is caused by an extremely rapid vibrating or rectilinear motion of molecules, and the hottest bodies are those in which the energy of this motion is greatest. The heat which a body contains is measured by the energy of motion of all its particles. To increase the temperature of the body is to increase this energy; to lower the temperature is to decrease it. Temperature is not the amount of heat energy but the measure of hotness in a body. A cup of water may bear the same temperature as a pail of water, still the quantity of heat energy in the pail far exceeds that in the cup as much more energy was expended in raising the temperature of the larger vessel.

b. In applying Charles' law to the contraction of a gas a very interesting discovery is made. If a given volume of gas having an initial temperature of 0° F. or C. is cooled under constant pressure it is found that for each degree that the gas is cooled it contracts by $\frac{1}{460}$ of its original volume for each degree drop in temperature Fahrenheit or $\frac{1}{273}$ of its original volume for each degree drop in temperature Centigrade. Hence, if the cooling were continued until a temperature of −460° F. was reached (or −273° C.) and the same rate of contraction continued up to this point the volume of gas would be reduced to nothing. This point, determined on the thermometer scale by theoretical considerations, is called the absolute zero, beyond which a further decrease in temperature is inconceivable. A temperature reckoned from this point instead of from the zero of the ordinary thermometers is called absolute temperature. So low a temperature has not been reached, but Charles' law is nearly accurate up to the point where the gas becomes a liquid. To find the absolute temperature in degrees F. or C., add 460 to number of degrees F. or 273 to number of degrees C., for example, to find the absolute temperature of the freezing point of water (32° F. or 0° C.)—

$460+32=492°$ absolute temperature F., or
$273+0=273°$ absolute temperature C.

c. In solids, due to molecular cohesion a molecule does not change its position in the body. In liquids and to a much greater extent in gases, the molecules are not held in position but are continually changing their position inside any container in which they may be inclosed, and it is easy to picture them as continually colliding with one another and the sides of the container. The total kinetic energy of a volume of a gas varies directly with the absolute temperature, and an increase of the temperature of an inclosed gas will either cause the pressure to rise due to the fact that a greater number of molecules strike a given surface in a given time and each molecule strikes at a greater average speed than before, or cause the volume to increase to the point where the same striking force, that is, the number of molecules per unit volume times weight of each molecule times average velocity of each molecule, will be exerted upon a given surface as before the temperature increase took place.

13. Application of Charles' law.—*a*. The first mathematical statement of the law governing the expansion of gases is credited to Charles, and stated mathematically is

$$V \propto T.$$

If the temperature of a gas is increased the volume will be increased, and if the temperature is decreased the volume will be decreased in direct proportion to the absolute temperature. Since the volume of a gas varies inversely as the density, it follows that the density varies inversely as the absolute temperature. Stated mathematically

$$D_g \propto \frac{1}{T}.$$

b. In accordance with Charles' law

$$\text{At constant pressure } V = V_o \frac{T}{T_o},$$

which shows that an increase in temperature will increase the numerator of the fraction

$$\frac{T}{T_o}$$

and therefore increase the original volume (V_o) to equal the expanded volume (V). Similarly when a temperature change takes place, the density of a gas is changed as follows:

$$\text{At constant pressure } D_g = D_{g_o}\frac{T_o}{T}.$$

(1) If 1,000 cubic feet of gas are inclosed in an elastic container at 32° F. and the temperature is increased 18° F., what will be the volume of the gas after expansion (assuming constant pressure)?

Solution.—The volume varies directly as the absolute temperature. The absolute temperature is 492° F. before the temperature increases. The absolute temperature becomes 510° F. after the temperature increases.

Then the volume becomes

$$V = V_o\frac{T}{T_o} = 1{,}000\frac{510}{492} = 1{,}000 \times 1.036 = 1{,}036 \text{ cubic feet.}$$

The change in volume or the additional volume is proportional to the change in temperature, or

$$\Delta V = V_o\frac{\Delta t}{T_o} = 1{,}000\frac{18}{492} = 1{,}000 \times 0.036 = 36 \text{ cubic feet.}$$

(2) If the density of the 1,000 cubic feet of gas above mentioned was 0.0111 pound per cubic foot before the temperature increased, what will be the density of the gas after the temperature is increased from 32° F. to 50° F.?

Solution.—The density varies inversely as the absolute temperature:

$$D_g = D_{g_o}\frac{T_o}{T} = 0.0111\frac{492}{510} = 0.0111 \times 0.964 = 0.0107 \text{ cubic foot.}$$

The density after the temperature increase is 0.0107, or a reduction of 3.6 percent, exactly the same percentage by which the volume was increased.

c. (1) Substituting the values of air and gas densities at standard pressure in the lift formula results in the following for a fixed volume of gas:

$$L = V(D_a - D_g)$$

$$= V\left(D_{a_o}\frac{T_o}{T} - D_{g_o}\frac{T_o}{T}\right) \text{ at standard pressure}$$

$$= V(D_{a_o} - D_{g_o})\frac{T_o}{T} \text{ at standard pressure.}$$

From this last equation it may be seen that the lift of a fixed volume of gas varies inversely as the absolute temperature.

(2) Where the volume is free to expand or contract the volume varies directly as the absolute temperature so that under the changes above

$$L=V\frac{T}{T_o}(D_{a_o}-D_{g_o})\,\frac{T_o}{T}$$

$$=V(D_{a_o}-D_{g_o}).$$

As long as gas and air temperature remain the same a change in air and gas density caused by a change in temperature is accompanied by and opposite and compensating change in volumetric displacement and there is no change in the lift of a volume of gas which is free to expand or contract. For this reason atmospheric temperature does not affect the lift of an airship which is below pressure height.

14. Application of Boyle's law.—*a.* The foregoing discussion showed the effect of a change in temperature upon volume and density, assuming that the pressure remained constant. But in actual practice the barometric pressure changes are almost as frequent as changes in temperature. In figuring lift it is necessary to take into consideration all changes in atmospheric pressure.

Boyle's law can be stated mathematically as follows:

$$V\propto \frac{1}{P}.$$

In accordance with Boyle's law—

At constant temperature $V=V_o\frac{P_o}{P}$.

Similarly, when a pressure change takes place, the density of a gas is changed as follows:

At constant temperature $D_g=D_{g_o}\frac{P}{P_o}$.

b. (1) Given a volume of air, the temperature of which is maintained at 32° F. Under a pressure of 29.92 inches its density is known to be 0.08072 pound per cubic foot. If the pressure is changed to "*P*" inches of mercury, the density will be changed as follows:

$$D_a=0.08072\,\frac{P}{29.92''}.$$

The volume is also changed by the change in pressure until

$$V = V_o \frac{29.92''}{P}.$$

(2) Consider 1,000 cubic feet of air inclosed in an elastic container, under standard conditions as stated above, and assume that the pressure changed to 30.5 inches. What would be the density of the inclosed air?

$$D_a = 0.08072 \frac{30.5}{29.92}$$

$$= 0.08072 \times 1.02$$

$$= 0.08230.$$

What would be the volume after the pressure increase?

$$V = 1{,}000 \times \frac{29.92}{30.5}$$

$$= 1{,}000 \times 0.98$$

$$= 980 \text{ cubic feet.}$$

c. Substituting the values of air and gas densities at standard temperature in the lift formula results in the following:

$$L = V(D_a - D_g)$$

$$= V\left(D_{a_o}\frac{P}{P_o} - D_{g_o}\frac{P}{P_o}\right) \text{ at standard temperature}$$

$$= V(D_{a_o} - D_{g_o})\frac{P}{P} \text{ at standard temperature.}$$

It is apparent that an increase in atmospheric pressure increases the lift of a fixed quantity of gas. However, where the gas is free to expand and contract the volume is changed in inverse proportion to the density, and the lift is unaffected by changes in atmospheric pressure.

d. Let the temperature and pressure both be varied in any manner. The effect on the volume can be found by the laws of Boyle and Charles and is the same as if first the temperature be changed at constant pressure and then the new volume so obtained be subjected to a change in pressure with the temperature held at the new temperature.

Denoting by V' the volume at the end of the change in temperature—

$$\text{By Charles' law: } V'=V_o\times\frac{T}{T_o}.$$

Now varying P_o to P with T constant:

$$\text{By Boyle's law: } PV=P_oV'$$
$$=P_oV_o\left(\frac{T}{T_o}\right)$$
$$\text{or } \frac{PV}{T}=\frac{P_oV_o}{T_o}.$$

This formula characterizes the most general transformation that any one gaseous mass can undergo. Two of the three elements, volume, pressure, and temperature, may be varied in an arbitrary manner and the third results therefrom. If the pressure and temperature, in particular, be arbitrarily varied, the volume is given by the following formula:

$$V=V_o\frac{P_o}{P}\frac{T}{T_o}$$

Let V, P, T denote the volume, pressure, and absolute temperature of a gas, and let the values P and T be changed to P' and T', respectively. Then V assumes the new value V', so that—

$$\frac{VP}{T}=\frac{V'P'}{T'}$$
$$VPT'=V'P'T.$$

This known as the isothermal expansion formula.

e. Sometimes it is more convenient to use a variation in the form of the expression for the change in volume caused by temperature changes at constant pressure. Suppose a volume of gas at standard conditions is subjected to a temperature change, the new temperature being $t°$, while P remains constant. By Charles' law—

$$V=V_o\frac{T}{T_o}$$
$$=V_o\frac{T_o+(t°-32°)}{T_o}$$
$$=V_o\left(1+\frac{t°-32°}{T_o}\right).$$

But $T_o=492°$.

Hence $V=V_o[1+a(t°-32°)]$ where $a=\frac{1}{492}$.

For every degree change in temperature starting at standard conditions, pressure remaining constant, the volume will vary $\frac{1}{492}$ of its original value. "*a*" is called the coefficient of expansion of gases. The formula above is accurately true for all gases used by the airship pilot, including air and water vapor, through the range of all temperatures encountered in flight.

15. Superheat.—*a*. It is the heat from the sun that warms the earth's surface, also the air, as well as the gas in the balloon. It might be expected that the temperature of the gas in a balloon floating in air would be the same as the temperature of the atmosphere itself, in the same way that the temperature of a body immersed in a liquid soon equalizes and the temperatures of the body and the liquid become the same. This is not the case, however, as a balloon or airship may contain gas that has exactly the same temperature as the air upon leaving the hangar, but a short time after the sun's rays have played upon it the temperature of the gas in the envelope increases to a much higher value than the atmospheric temperature. In the case of a rubberized envelope not in motion in reference to the atmosphere, the increase of temperature may be as much as 30° F. in extreme cases, and a much greater increase is possible in the case of a varnished free balloon.

b. This increase in gas temperature is due to the light rays being changed to heat as they pass through the envelope. It is the same effect that takes place in a greenhouse or tent. On a sunny day the temperature in a greenhouse or tent that is not ventilated is always higher than the temperature of the surrounding air. The pilot will notice changes in lift as the sun disappears behind the clouds, or after sunset, which are caused primarily by the reduction in superheat and not by changes in atmospheric temperature.

c. The subject of superheat is one of the easiest parts of aerostatics, and at the same time, one of the most important. The effects of an increase or decrease in superheat are directly noticed and are always of sufficient magnitude to render them of importance. Whenever the temperature of the gas inside an airship envelope becomes greater without a corresponding change in that of the surrounding air, the airship picks up additional lift due to the increased volume and decreased density of the expanded gas. On clear days when the sun is shining brightly, the temperature of the gas inside an airship envelope is always higher than that of the surrounding air and the lift is consequently greater than that computed by using the air temperature only. This difference between the temperature of the gas and that of the outside air is called superheat. Superheat may be either positive or negative. It is always positive during hours of sunshine and reaches the negative condition at night.

d. If sunshine strikes the outer cover of the rigid airship or the envelope of the nonrigid, some of its heat energy will be absorbed by the gas and the temperature of the inclosed gas will be increased. As soon as this happens, the inclosed gas will begin to expand, and when the airship is not full of gas (below pressure height) the volume of gas will be increased.

16. Computation of effects of superheat.—*a.* (1) In the case of a rigid airship with superheat, no gas is lost due to expansion until the cells become full. The weight of the gas thus remaining constant while the airship is below pressure height, the increase in lift equals the weight of the additional air displaced. Above pressure height, the increase in lift equals merely the weight of gas valved since the air displacement remains constant. In the case of a nonrigid airship, as soon as superheating takes place and the inclosed gas begins to expand, the pilot will have to valve (air when possible) to keep down the manometric pressure. Since both air and gas have weight and the phenomena of superheat has no effect upon the weight of the outside air displaced by the airship, the lift of the airship will be increased by an amount exactly equal to the weight of the air (or gas) valved. Cusomarily any superheating of air in the ballonets of nonrigids is negligible.

(2) If the volume of gas inside the airship without superheat is called V, the volume of gas after superheating, V', the absolute temperature of the air, T, the superheat ΔT_g and the additional lift gained from superheating ΔL, then below pressure height—

$$V' = V\frac{T+\Delta T_g}{T} = V\frac{T'_g}{T_g}$$

and the increase in volume of the gas $= V' - V = \Delta V$

$$\Delta V = \left(V\frac{T+\Delta T_g}{T}\right) - V$$

$$= V\left(\frac{T+\Delta T_g}{T} - 1\right)$$

$$= V\left(\frac{T+\Delta T_g}{T} - \frac{T}{T}\right)$$

$$= V\frac{\Delta T_g}{T}.$$

The increase in lift due to superheating will be equal to the weight of ΔV of air, or—

$$\Delta L = \Delta V D_a$$
$$= D_a V \frac{\Delta T_g}{T}.$$

If the air is dry the additional lift—

$$\Delta L = 1.327 \frac{P}{T} V \frac{\Delta T_g}{T}$$
$$= \frac{1.327 \, V P \, (\Delta T_g)}{T^2}.$$

This formula involves a simple slide rule or logarithmic computation which can best be understood by a practical problem.

Example.—An airship of 300,000 cubic feet capacity is brought out of its hangar on a day when the sun is shining. The atmospheric temperature is 50° F. and the pressure 30 inches of mercury. The airship has 50,000 cubic feet of air in its ballonets, which leaves the volume of gas 250,000 cubic feet before superheating. How much lift will the airship pick up if the gas in the envelope is superheated 15° F. before the airship takes off?

Assuming the air to be dry—

$$\text{Increase of lift} = \frac{1.327 \, V P \, (\Delta T_g)}{T^2}$$
$$= \frac{1.327 \times 250{,}000 \times 30 \times 15}{(510)^2} = 574 \text{ pounds.}$$

b. The superheating which interests us most directly is caused by the sun's rays over which no control is had. But if a heating arrangement is provided whereby the gas can be heated by the exhaust from the motors or the airship is held in the sun until a certain lift is accomplished, the necessary amount of superheat can be computed directly as follows:

$$\Delta L = D_a \, V \frac{\Delta T_{g'}}{T}$$

$$\Delta T_g = \frac{\Delta L \, T}{D_a V}.$$

And for dry air the necessary superheat becomes—

$$\Delta T_g = \frac{\Delta L\ T}{V\ 1.327\ \frac{P}{T}}$$

$$= \frac{\Delta\ L\ T^2}{V\ 1.327\ P}.$$

c. When an airship is brought out of its hangar into the sunshine the manometric pressure will be seen to rise immediately the airship begins to emerge from the shade of the hangar and within a very few seconds the pilot has to valve air to prevent overpressure. Each pound of air valved from the ballonet becomes one more pound of added lift; and if no other means is provided the amount of superheating can be determined before leaving the ground by the gain in lift as determined from the difference in the weigh-off in the hangar and outside, using the formula given above.

d. If the maximum lift is desired, the airship will be held on the ground until no more superheat is being gained and the manometer reading remains practically constant. As soon as the airship takes off, cooling begins and the airship will become somewhat heavy, and this added weight must be carried dynamically. If the dynamic load is too great, speed of the airship will be reduced greatly. Also, if the airship becomes too light due to superheating, it becomes necessary to counteract the positive buoyancy by downward or negative dynamic force, which will also greatly reduce the speed. It may be seen readily that it is not an economy to let the airship get too heavy or too light, but is advisable to keep it as nearly as possible at equilibrium in order to accomplish the maximum headway. A very interesting example of this is given in the log of the trans-Atlantic flight of the *R-34*. It may be seen easily that the effect of superheat is not always helpful.

e. Normally when taking off in a nonrigid airship, a pilot flies to a sufficiently great height to clear all obstacles in his immediate vicinity, valving air to take care of the pressure as he climbs; he then climbs more slowly to equalize his manometer reading as the superheat is slowly reduced by conduction. If the pilot knows the altitude from which he started climbing without valving air and the altitude which he reached in equalizing pressure due to superheat loss, it is possible to approximate closely the amount of lift lost. This loss of lift is the difference in weight between the total volumes of displaced air at the two altitudes, or the loss in lift is equal to the weight of $V\,D_a$ at the first altitude minus the weight of $V'\,D_a'$ at the final altitude.

f. Obviously, if the air in an airship's ballonets becomes heated, this air will weigh less than the outside air and will add lift to the airship. The effect is exactly the same as in the case of the old "hot-air" balloon. The ballonet lift is the difference between the weight of the inside air and that of the outside air. The weight of the outside air is—

$v\,D_a$, where v is volume of air in the ballonets.

The weight of the inside air is—

$$V\,D_a\left(\frac{T}{T+(\Delta T)}\right).$$

The lift of the superheated ballonets becomes—

$$v\,D_a - v\,D_a\frac{T}{T+(\Delta T)}$$

$$v\,D_a\left(\frac{\Delta T}{T+\Delta T}\right).$$

For the sake of simplicity, the following formula is sufficiently accurate:

$$\text{Ballonet lift} = v\,D_a\frac{\Delta T}{T}.$$

For dry air this becomes—

$$\text{Ballonet lift} = v\,1.327\frac{P\,\Delta T}{T\,T}$$

$$=\frac{1.327\,v\,P\,\Delta T}{T^2}.$$

Example.—Compute the additional lift of a 300,000-cubic-foot airship originally having 50,000 cubic feet of air in its ballonets if the gas becomes superheated 15° F. and the air in ballonets becomes superheated 10° F. Consider air to be dry, pressure 30 inches of mercury, and temperature 50° F.

$$\text{Lift due to superheat of gas} = \frac{1.327\ PV'\ (\Delta T_g)}{T^2}$$

$$= \frac{1.327 \times 30 \times 250{,}000 \times 15}{(510)^2}$$

$$= 574 \text{ pounds.}$$

$$\text{Final volume of gas} = 250{,}000 \times \frac{525}{510} \text{ (Charles' law)}$$

$$= 257{,}300 \text{ cubic feet.}$$

$$\text{Air in ballonets} = 300{,}000 - 257{,}300 \text{ cubic feet}$$

$$= 42{,}700 \text{ cubic feet.}$$

$$\text{Lift due to superheat in ballonets} = \frac{1.327\ v\ P\Delta T}{T^2}$$

$$= \frac{1.327 \times 42{,}700 \times 30 \times 10}{510 \times 510}$$

$$= 65.3 \text{ pounds.}$$

$$\text{Total gain in lift} = 639 \text{ pounds.}$$

The small value of the ballonet lift shows that this computation is not necessary.

Section V

HUMIDITY

(Variable "*e*")

17. Effects of atmospheric humidity.—All the calculations which have been made so far in explaining effects of the different variables entering into the lift formula have been made on the assumption that the air is dry. This is permissible for approximate calculations, but in practice the atmosphere is never found dry or completely without moisture. The small amount of water vapor held in suspension in the atmosphere is almost negligible under certain conditions, but conditions do arise in practice where it is of the utmost importance to know actual conditions of the atmosphere with respect to its vapor content. It should be realized by the pilot that it is always important to know condition of the air as to relative humidity and the possibility of picking up weight by collecting moisture from the air which is nearing the dew point. He should know at all times the probability of the air reaching the saturation point and of his encountering rain.

18. Methods of determining humidity factor.—*a*. The correction is very easy to make and consists of two steps; first, to determine the humidity factor; second, to correct the lift formula for humidity. First it will be shown how "*e*", the humidity factor, is determined.

(1) There are several methods of determining the moisture content of the atmosphere, but only two practical methods will be mentioned here. The method adopted by airship pilots is by reading the wet- and dry-bulb thermometers. The theory of this method is that an evaporating liquid absorbs heat. Thus, if the mercury bulb of a thermometer is kept moist (which is usually accomplished by covering it with a piece of absorbent cloth dipped in water) and the thermometer is swung around in the air, the temperature registered by the thermometer will drop until it reaches a definite value, which is always lower than the temperature of the dry-bulb thermometer swung with it, except when the relative humidity is 100 percent and the air is completely saturated with water vapor. This is due to the fact that when the air is completely saturated no water will be evaporated from the saturated cloth on the thermometer bulb. Then the drier the air and the higher the temperature the faster will be the evaporation of the water.

(2) It was stated that evaporating liquid absorbs heat which is one way of stating the phenomena, but the actual theory of lowering of temperature by evaporation is that in order to vaporize liquid it must be expanded and thrown off into space in small particles of matter (or vapor) and whenever a gas or vapor is expanded without addition of heat energy temperature of the mass is lowered. Therefore, the temperature of the (expanding) vaporizing water on the bulb lowers the temperature of the water, and this is recorded by the thermometer. The difference in the reading between the wet and dry bulb depends entirely upon the amount of water vapor present in the air at a given temperature.

(3) Another method of determining accurately the amount of water vapor in the air is by hygrometers. One type of hygrometer determines the humidity by weighing the water vapor contained in a volume of moist air after such water vapor has been absorbed by absorption tubes carefully calibrated. This amounts to direct measurement of the density (*D*) of the water vapor.

(4) For any given temperature "*e*" is equal to a certain value, which is called the maximum vapor pressure of water vapor at that temperature. When such value has been attained the water vapor

begins to condense and form small drops; in other words, it rains. Inversely, if the tension of water vapor in a gaseous mass is lower than saturation, water, when brought in contact with the gas, vaporizes. At the end of a sufficient time a gaseous mass in contact with water will be saturated. The maximum vapor pressure of water vapor continues to increase steadily with the temperature; that is to say, the higher the temperature the greater the amount of water vapor the air will sustain.

b. The most accurate method and the method which is recommended for determining "*e*" is by use of the psychrometric tables published by the United States Department of Agriculture, which give "*e*" for every condition of pressure and temperature found in practice. As there is a probability of being without a psychrometric table at a time when it is desired to determine the humidity factor, a table has been provided in section XIV by which the value of the vapor pressure or the *partial pressure* of the water vapor present in the air can be determined, as follows:

Look in Table I for the figure corresponding to the dry-bulb thermometer reading in degrees F. in the column headed "Reading of dry bulb." Then look in the column to the right and find the "Glaisher's factor" corresponding to this temperature. Multiply this "Glaisher's factor" by the difference between the dry-bulb thermometer reading and that of the wet-bulb thermometer in degrees F. Subtract the the result from the dry-bulb thermometer and that gives the "dew point" or the temperature at which the atmosphere would be saturated completely with water vapor with the existing amount of this vapor. Then look in the column headed "Temperature of dew point" for the number corresponding to the "dew point" in degrees F., and in the column to the right of this number will be found a figure which is three-eighths of the water-vapor pressure.

19. Correcting for humidity.—The method of correcting the lift formula for humidity will best be understood by developing the formula as follows:

a. The molecular weight of water vapor is 18 and the approximate molecular weight of air is 28.8. This shows that moist air is lighter than dry air. Water vapor from the figures given above will be seen to weigh $\frac{18}{28.8}$ as much as air, or roughly $\frac{5}{8}$ as much as air. This means that the portion of the atmosphere which consists of water vapor weighs $1\frac{5}{8}$, or $\frac{3}{8}$ less than it would if it too were dry air. From the theory of partial pressures of a mixture of gases, the weight of a cubic foot of wet air is equal to the weight of the dry air in the space plus the weight of the water vapor therein. Hence when the space of

1 cubic foot is occupied by both air and water vapor the mixture will weigh less than an equal volume of dry air, as a certain portion of the dry air has been displaced by water vapor, and the total weight of this mixture will depend upon the amount of water vapor present.

b. To correct the density of the air volume for the amount of water vapor contained therein, the practice has been adopted of correcting the atmospheric pressure by subtracting from it $\frac{3}{8}e$, three-eighths of the vapor pressure.

c. The pressure of the water vapor contained in the atmosphere is the pressure which the water vapor would have sustained in a determined volume, supposing that it occupied all that volume alone. Such pressure is called tension of water vapor in air and is denoted by the letter "e." According to the law, the pressure of dry air contained in that volume and made to occupy alone the whole volume would thus be $P-e$, where P is the atmospheric pressure, that is, the pressure to which the mixture is subjected. If the temperature of the moment be denoted by T, the weight of dry air contained in the volume is equal to

$$D=V\times 1.327\frac{P-e}{T}$$

and the density of the water vapor contained in the same volume is

$$D'=V\times 1.327\frac{e}{T}\times\frac{5}{8}$$

or $\frac{5}{8}$ density dry air would have at pressure "e." The density of the mixture is equal to the sum of the densities of dry air and water vapor, or

$$D_a=D+D'$$

which may be expressed as follows:

$$D_a=\left(1.327\times\frac{P-e}{T}\right)+\left(1.327\times\frac{e}{T}\right)\tfrac{5}{8}$$

$$=\left(1.327\times\frac{P}{T}\right)-\left(1.327\times\frac{e}{T}\right)+\left(1.327\times\frac{\frac{5}{8}e}{T}\right)$$

$$=1.327\frac{P-e+\frac{5}{8}e}{T}$$

$$=1.327\times\frac{P-\frac{3}{8}e}{T}$$

$$=1.327\times\frac{P-0.38e}{T}.$$

20. Relative humidity.—Relative humidity is the ratio of the actual existing condition of vapor pressure to the vapor pressure at saturation under the same conditions of pressure and temperature.

$$\text{Relative humidity} = \frac{\text{Vapor pressure (actual)}}{\text{Vapor pressure (saturated)}}.$$

21. Correcting density constant for humidity.—*a.* If the average is taken, it is found that 60 percent relative humidity is the most frequent condition found. Therefore this figure will be adopted in the following approximation. By adopting this average humidity condition and correcting the density accordingly the maximum error will be small.

b. What will be the correction for the density constant of air when the temperature is 50° F., the barometer 29.92 inches, and the relative humidity 60 percent?

$$K' = 1.327\, \frac{P_o - 0.38e}{P_o}$$

$$= 1.327\, \frac{29.92 - 0.38 \times 0.216}{29.92}$$

$$= 1.323.$$

c. It is desirable to take the effect of 60 percent relative humidity at a mean temperature of 50° F. so that actual errors resulting in the lift formula will not always accumulate in one direction.

(1) When the temperature is higher than 50° F. the resultant lift solution will be too great.

(2) When the temperature is lower than 50° F. the resultant solution is too small.

(3) When the relative humidity is greater than 60 percent the result is too large.

(4) When the relative humidity is less than 60 percent the result is too small.

d. When a practical degree of accuracy is desired apply the following rule:

(1) Use the dry formula for temperature below freezing (32° F.).

(2) Use corrected K' for temperatures from 32° to 50° F.

(3) Use actual humidity corrections for all higher temperatures.

e. It is desired to correct the idea that humidity is a negligible factor. The larger the airship the more important is the humidity factor. Unfortunately the effect of humidity is greatest when the total lift of the airship is the least.

f. A very simple method of getting the relative humidity in flight is as follows: Read the dry-bulb temperature at the airship's ventilated thermometer, then wet the bulb and keep it wet for a time by sprinkling and read the temperature after a couple of minutes. The second reading will serve as a wet-bulb reading for use in the tables.

Section VI

PURITY AND SPECIFIC GRAVITY OF GAS

(Variables "Y" and "S")

22. Effect of gas purity upon lift.—*a*. The gases used to inflate lighter-than-air aircraft are seldom free from impurities. The pressure of these impurities increases the density of the inflating gas and decreases its lift.

b. Although the impurities may be composed of various substances such as dry air, water vapor, or carbon dioxide, for purposes of lift calculations all impurities may be considered to be dry air. The error so introduced is negligible and on the side of safety.

c. The ratio of the total volume of pure gas to the total volume of gas is called the gas purity and is denoted by the letter Y. Since the volume of impurities is considered to be air, it exerts no lift but is self-supporting in air, merely acting to reduce the displacement of the pure gas. Thus a volume of gas, V, which has a purity of 95 percent is considered to contain a volume of pure gas equal to 95 percent V exerting the lift of pure gas and a volume equal to 5 percent V of air giving no lift at all.

23. Application of purity factor.—*a*. Take, for instance, 1,000 cubic feet of impure hydrogen which is of 95 percent purity.

(1) Then Y equals 0.95 and $1-Y$ equals 0.05, and the mixture is 0.95 by volume pure hydrogen and 0.05 by volume air.

$$\begin{aligned} VD_g &= VD_{go}Y + VD_{ao}(1-Y) \\ VD_g &= (5.62\times 0.95) + (80.71\times 0.05) \\ &= 5.34 + 4.03 = 9.37 \text{ pounds} \\ &= \text{weight of the impure gas.} \end{aligned}$$

Under the above conditions the 1,000 cubic feet of impure gas will lift—

$$L = VD_a - VD_g = 80.7 - 9.4 = 71.3.$$

80.7 is the weight of 1,000 cubic feet of dry air.

(2) Pure hydrogen will lift an amount equal to the difference between the weight of air and of pure hydrogen.

For 1,000 cubic feet of the pure gas under standard conditions—

$$L = 80.7 - 5.6 = 75.1 \text{ pounds}$$

$$\frac{\text{Lift of the impure gas}}{\text{Lift of the pure gas}} = \frac{71.3}{75.1} = 0.95 = Y.$$

The lift of pure hydrogen multiplied by the purity factor equals the lift of the impure gas.

$$75.1 \times Y = L = 75.1 \times 0.95 = 71.3 \text{ pounds.}$$

b. This suggests one method cf determining the purity factor Y by determining the density of the gas in question and determining the ratio of its lift to that of the pure gas, as follows:

Suppose the gas has been tested and found to have a density of 0.0094 under standard conditions and it is desired to determine Y, then—

$$\text{Purity} = \frac{D_{ao} - D'_g}{D_{ao} - D_{go}} = \frac{0.0807 - 0.0094}{0.0807 - 0.0056} = \frac{0.0713}{0.0751} = 0.95.$$

c. Another and simpler method of determining the purity factor "Y" is accomplished by the use of the specific gravities of the impure and pure gas. Substituting the value of the specific gravity of gas in the above expression—

$$\text{Purity} = \frac{D_{ao} - D'_g}{D_{ao} - D_{go}} = \frac{D_{ao}\,(1 - S')}{D_{ao}\,(1 - S)}$$

$$Y = \frac{1 - S'}{1 - S}$$

where S' is the specific gravity of the impure gas and S that of pure gas.

24. Use of 1−S as lift factor.—*a.* It was shown above that in order to determine the factor Y the specific gravity or density must first be determined; then by use of the given formulas, the purity. The process can be greatly simplified by eliminating the use of Y and substituting the value $(1-S)$, which takes care of all the impurities and humidity of the gas.

b. Substituting the value of D_g in the lift formula—

$$L=V\ (D_a-D_g)$$
$$L=V\ (D_a-D_aS)$$
$$L=VD_a\ (1-S)$$
$$L=VK\frac{P}{T}\ (1-S)$$

if the superheat and humidity factors be ignored.

25. Determination of gas density and specific gravity.—*a*. It has been determined by scientific experimentation that *two equal volumes of two gases under the same pressure require time in proportion to the square roots of their densities to flow through a capillary opening*, or, the time required for a gas to flow through a capillary opening varies as the square root of the density.

b. This measurement is accomplished by the Schilling apparatus. If r and R represent the time required by equal volumes of hydrogen and air in flowing through the orifice, the statement of the law becomes—

$$\frac{r}{R}=\sqrt{\frac{D_g}{D_a}}$$

from which it is possible to compute the density of the gas. Squaring both sides of the equations—

$$\frac{r^2}{R^2}=\frac{D_g}{D_a}=\text{specific gravity of the gas.}$$

c. The density of the gas at 32° F. (0° C.) and 29.92 inches (760^{mm}) is computed from the formula above.

$$D_g=D_{a_o}\times\frac{r^2}{R^2}=0.08072\times\frac{r^2}{R^2}.$$

NOTE.—In order to simplify computations it is convenient to have a table in which the lifting power is given in terms of r/R. Such a table is furnished with the Schilling apparatus and will not be furnished in this manual as it would never be of service to the pilot in flight.

SECTION VII

COMPLETE DEVELOPMENT OF LIFT FORMULAS

26. Simple lift formula.—As indicated in paragraph 11*e*, all the variables entering into the solution of the lift formulas have been treated separately under the headings of the variables, P, T, Y, S, D, and e, and will now be combined into development of the standard lift formulas.

a. The lift of any volume of buoyant gas contained within an envelope is equal to the difference between the weights of the displaced air and the weight of the buoyant gas, or—

$$\text{Lift}=V\,(D_a-D_g).$$

b. Determination of lift therefore becomes a matter of determining densities of the atmospheric air and of the gas used. The densities of air or gas can be determined as follows:

$$D_a=D_{ao}\frac{T_oP}{P_oT}=K\frac{P}{T}$$

$$D_g=D_{go}\frac{T_oP}{P_oT}=C_g\frac{P}{T}$$

As previously explained, the value $D_{ao}\ T_o/P_o$ is always the same and can therefore be combined into a constant for either air, hydrogen, or helium, as follows:

$$K=D_{ao}\frac{T_o}{P_o}=0.08072\frac{492}{29.92}=1.327$$

$$\text{and } C_g'=D_{go}\frac{T_o}{P_o}=0.00562\frac{492}{29.92}=0.092$$

$$\text{Then } C_g=D_{go}\frac{T_o}{P_o}=0.01114\frac{492}{29.92}=0.183.$$

c. By substituting the specific gravity of the gas used for the density value the formulas can be simplified and the need for subtracting the two densities can be eliminated, at the same time taking care of the impurities and the humidity of the gas.

$$L=V(D_a-D_g)$$

$$L=V(D_a-D_aS)$$

$$L=VD_a(1-S)$$

$$L=VK\frac{P}{T}(1-S).$$

Since airships are not always completely full of gas, the expression FV gives the gas volume. Substituting FV for V, the formula becomes—

$$L=FVK\frac{P}{T}(1-S).$$

This formula is accurate at all times when the air is dry and the air and gas temperatures are the same.

27. Lift formula with humidity correction (*LF*–1).—Since the atmospheric density varied with humidity for moist air—

$$D_a=K\frac{P-0.38e}{T}.$$

Hence the lift formula is changed by humidity as follows:

$$L=VK\frac{P-0.38e}{T}(1-S).$$

Since S is based on dry air, this formula contains a slight but negligible error.

28. Lift formulas with corrections for superheat.—*a.* Superheat has two different effects on the lift, according to whether the airship is flying partially or completely full of gas.

(1) Below pressure height, when the gas at atmospheric temperature becomes superheated its volume increases and its density decreases. The lift is still the difference between the weight of the air displaced and the weight of the gas. Hence

$$L=FV(D_a-D'_g)$$

where D'_g is the gas density and F the percentage of fullness after expansion.

$$D'_g=\frac{T_a}{T_g}D_g=\frac{T_a}{T_g}D_aS$$

$$\text{Hence } L=FV\left(D_a-D_aS\frac{T_a}{T_g}\right)$$

$$=FVD_a\left(1-S\frac{T_a}{T_g}\right)$$

$$=\frac{FVKP\ (T_g-T_aS)}{T_a\times T_g}. \quad (LF\text{–}2.)$$

(2) Correcting this last statement for humidity gives the formula—

$$L=FVK\frac{(P-0.38e)\ (T_g-T_aS)}{T_a\times T_g}.$$

This formula is very useful in rigid operation during flight because F can be determined by inspection of the cells.

b. When the airship reaches pressure height, expansion due to superheat cannot increase the volume, so gas must be valved to maintain constant pressure. The remaining gas occupies the same volume but has reduced density. As before, the basic lift relation holds as does the derived formula—

$$L=FVK\frac{(P-0.38e)\ (T_g-T_a\ S)}{T_a\times T_g},\ F\text{ being 100 percent.}$$

In this case, however, the increase in lift caused by superheat is due solely to the decrease in D_g and not due to an increase in F, as is the case when below pressure height.

c. When below pressure height the gain in lift is exactly equal to the gain in the weight of the air displaced.

$$\Delta V=FV\frac{\Delta T_g}{T_a}$$

$$\text{Hence }\Delta L=\Delta VD_a$$

$$=\frac{FV\Delta T\ K(P-0.38e)}{T_a^2}.$$

d. When the airship is full of gas the gain in lift equals the weight of gas valved; in other words, the difference between the total weight of gas in the airship before and after expansion.

$$\Delta L=V(D_g-D'_g)$$

$$=V\left(SD_a-D_a\ S\frac{T_a}{T_g}\right)=VSD_a\left(1-\frac{T_a}{T_g}\right)$$

$$=VSK\frac{P}{T_a}\times\frac{\Delta T_g}{T_g}.$$

e. Combining the lift formula without superheat with the formula for the gain in lift due to superheat below *P. H.* results in the following formula for the lift with superheat:

$$L'=FVK\frac{P-0.38e}{T_a}(1-S)+FVK\frac{(P-0.38e)\Delta T_g}{T_a^2}.$$

NOTE.—In this formula F is the percentage of fullness without superheat.

f. If a certain amount of superheat, Tg, exists, and a further change in the superheat, T_g, is encountered the new lift is given by the formula—

$$L'=FVK\frac{(P-0.38e)\ (T_g-T_a\ S)}{T_a\times T_g}+FV\frac{\Delta T'_g}{T_g}K\frac{(P-0.38e)}{T_a}.\ (LF\text{-}3.)$$

g. A close approximation of the lift after superheat can be made by assuming the lift to vary directly as the volume before and after expansion. Then

$$L' = L\,\frac{T_g}{T_a}.$$

29. Three problems of determining lift.—There are in reality three different types of lift problems as shown in the preceding development of the lift formulas.

a. Problem No. 1 (*LF*–1).—To determine the lift of an airship when the air and gas temperatures are the same (or without superheat). A nonrigid airship of 250,000 cubic feet capacity is filled with helium gas having a specific gravity of 0.213. The atmospheric temperature is 60° F., and the barometric pressure is 30 inches of mercury.

(1) What is the lift of the airship full of gas?

Solution:

$$L = \frac{250{,}000 \times 1.327 \times 30}{460 + 60}\,(1 - 0.213)$$

$$= 15{,}060 \text{ pounds.}$$

(2) What will be the lift when the relative humidity is 75 percent?

Solution.—From Table No. I, the value 0.38*e* at saturation is 0.19. With 75 percent relative humidity, $0.38e = 0.75 \times 0.19 = 0.142$—

$$L = \frac{250{,}000 \times 1.327\ (30 - 0.142)}{520}\,(1 - 0.213)$$

$$= 15{,}000 \text{ pounds.}$$

b. Problem No. 2 (*LF*–2).—What will be the lift of the airship given in Problem No. 1 (*a* (2) above) if the superheat value (ΔT_g) is 20° F.?

Solution:

$$L = \frac{250{,}000 = 1.327\ (30 - 0.142)\ (540 - 520 \times 0.213}{520 \times 540}$$

$$= 15{,}160 \text{ pounds.}$$

c. Problem No. 3 (*LF*–3).—The same airship of 250,000 cubic feet capacity leaves the surface in equilibrium, *without superheat*, and 90 percent full of gas with a specific gravity of 0.213. After flying for a short time, the superheat value reaches 20° F.

(1) What is the lift at the time of leaving the surface?

Solution.—As the airship is now only 90 percent full at surface and has no superheat—

$$L=\frac{0.90\times 250{,}000\times 1.327\ (30-0.142)}{520}\ (1-0.213)=13{,}500 \text{ pounds.}$$

(2) What is the increase in lift after the superheating takes place and what is the total new lift?

Solution.—No gas is lost in flight due to superheating or ascent.

$$\Delta L=\Delta V\ D_a=FV\frac{\Delta T_g}{T_a}K\frac{(P-0.38e)}{T_a}$$

$$\Delta L=\frac{0.90\times 250{,}000\times 20\times 1.327\times 29.86}{520\times 520}$$

$$=660 \text{ pounds}$$

$$L'=L+\Delta L$$

$$=13{,}500+660=14{,}160 \text{ pounds.}$$

Problem No. 3 (2) is capable of solution by *LF*–2.

After expansion

$$\text{F}=0.90\times\frac{\Delta T_g}{T_a}\frac{0.90\times 540}{520}=0.935$$

$$\text{L}'=\frac{0.935\times 250{,}000\times 1.327\times 29.86\ (540-520\times 0.213)}{520\times 540}$$

$$=14{,}160 \text{ pounds.}$$

Section VIII

SUPERPRESSURE OR INTERNAL GAS PRESSURE

30. Effect of interior gas pressure upon lift.—*a*. In the preceding sections in considering the pressure sustained by gaseous volumes and the effect upon the density of the lifting gas caused by changes in pressure, no account has been taken of the additional internal pressure sustained by the gas in nonrigid airships. Just as the internal heat of the gas over the outer air was termed superheat, this internal excess of pressure will be called superpressure of the gas.

b. The superpressure is the pressure as shown on the manometer and is additional pressure over any existing atmospheric pressure. As the manometric reading is in inches or millimeters of water and the barometric reading is in inches or millimeters of mercury, the pressure indicated by the manometer is very small in comparison to the atmospheric pressure. For instance, the maximum manometric pressure of airships in flight is 1.5 inches of water. A mercury column of 29.92 inches is equal in weight to a water column of 34 feet, or 408 inches. Hence the interior superpressure in comparison with the total atmospheric pressure of 29.92 inches is

$$\frac{1.5''}{408''}=0.0037$$

which shows that the density of the gas is changed only 0.0037, or approximately one-third of 1 percent by the total supercompression under the above conditions. But actually the internal gas pressure will be greater than that recorded on the manometer due to the error in its reading caused by the manometer being located below the gas container. On account of the difference between the density of the gas column above the manometer and the density of the surrounding air, the superpressure varies from its lowest value at the manometer to its highest at the top of the envelope. Where the manometer is 100 feet below the highest point of the envelope this increase in superpressure amounts to 1.4 inches of water pressure.

c. Suppose an airship ascends to an altitude where the atmospheric pressure is reduced to 15 inches of mercury, then the superpressure of 1.5 inches of water will affect the density as

$$\frac{1.5}{204}=0.0073$$

or approximately seven-tenths of 1 percent. This shows that the small change in lift due to the internal manometric pressure is negligible, except where extreme accuracy is desired. This change in density can always be determined by the ratio of the superpressure to the atmospheric pressure.

$$\text{Percentage change in gas density}=\frac{\Delta P}{P}$$

where ΔP is the superpressure.

31. Correction of lift formula to include effects of superpressure.—The following formulas are given more as a matter of interest than of practical value, but will enable the determination of the effect upon lift when extreme accuracy may be desired.

$$L=\frac{FVKP}{T}(1-S)$$ when there is no differential pressure between the air and gas.

$$L=\frac{FVKP}{T}\left(1-S\frac{P+\Delta P}{P}\right) \text{ with superpressure}$$

$$=\frac{FVKP}{T}\left(1-S\frac{P'}{P}\right)$$

$$=\frac{FVK\ (P-P'S)}{T}$$

$$=\frac{FVK[(P-0.38e)-P'S]}{T} \text{ including the humidity correction.}$$

Section IX

ATMOSPHERIC VERTICAL TEMPERATURE AND PRESSURE GRADIENT AND DETERMINATION OF ATMOSPHERIC DENSITY AT ANY ALTITUDE

32. Atmospheric vertical temperature gradient.—The temperature of the atmosphere is not the same at different altitudes. Instead of remaining constant, its decrease is almost constant with increase of altitude.

a. The gases composing the atmosphere have very small absorbing power. Although very pervious to heat they retain very little. They do not heat by radiation but by conductivity. Thus the lower strata of the atmosphere by contact with the ground assumes the average surface temperature. The following layers by contact with the latter and by circulation are also heated to a lesser degree, which creates a constant temperature decrease. But the phenomenon is not always regular due to differences of temperature at different points on the earth's surface and consequent circulation and mixing of the atmosphere. To this must be added disturbances caused by clouds which absorb the heat rays and heat the masses of air by contact. Heat from the rays of the sun is only collected when intercepted. If the rays meet an obstruction they are arrested in their travel and heat collects on the intercepting object. The earth's surface and clouds floating in the air obstruct the rays and readily collect heat.

b. It has been found by experiment that for every 300 feet increase in altitude the temperature decreases 1° F. Actually the temperature gradient does not hold true under all conditions near the earth's surface, but is reasonably accurate above the first 2,000 feet of altitude, and the rate of decrease remains almost constant until the stratosphere is reached, which is between 30,000 and 40,000 feet, after which the temperature remains almost constant in ascending.

33. Homogeneous height.—The atmospheric density decreases with altitude due to the constantly decreasing head of atmospheric pressure. If the total mass of air in the atmosphere had a uniform density equal to the density at the surface, the height to which this atmosphere would extend would be materially reduced. This height is called the homogeneous height.

a. Dividing the standard atmospheric pressure per square foot by the standard air density gives—

$$H=\frac{14.75\times 12^2}{0.0807}=26{,}300 \text{ feet, the homogeneous height under standard conditions.}$$

b. In such atmosphere the pressure drop between any altitude h and the surface is to the surface pressure as the height h is to the total homogeneous height, thus:

$$\frac{h}{26{,}300}=\frac{P-P'}{P}, \text{ where } P' \text{ is the pressure at altitude } h.$$

However, this formula is not sufficiently accurate for altitude-pressure computations.

34. Accurate altitude-pressure relations.—*a.* It has been determined by Halley that the actual decrease in pressure with increasing altitude is a logarithmic law. He gives the following formula:

$$h=26{,}300 \operatorname{Log}_e \frac{P_o}{P'}.$$

To change to the system of common Logs—

$$h=26{,}300\left(\operatorname{Log}_e \frac{P_o}{P'}\times\frac{1}{\text{modulus } \operatorname{Log}_{10}}\right)$$

$$=26{,}300\left(\operatorname{Log}_{10} \frac{P_o}{P'}\times 2.30259\right)$$

$$=(26{,}300\times 2.30259) \operatorname{Log}_{10} \frac{P_o}{P'}$$

$$=60{,}600 \operatorname{Log}_{10} \frac{P_o}{P'}.$$

With an increase in barometric pressure at the earth's surface there will be no increase in the homogeneous height as originally obtained for the reason that as the pressure increases the atmospheric density increases directly in proportion. This fact enables use of any given surface pressure P instead of the original standard condition of pressure P_o without a correction to the value 60,600. Hence, Halley's formula assumes the form:

$$h=60{,}600 \text{ Log} \frac{P}{P'}.$$

b. At 60,600 the value P/P' becomes equal to 10 and its logarithm is equal to 1. Therefore, the height where the pressure becomes $\frac{1}{10}$ surface pressure is equal to 60,600 feet, and is called height at $\frac{1}{10}$.

c. The above formula makes no allowance for variations in atmospheric temperature or humidity. The complete formulas are as follows:

$$L=60{,}600\,[1+0.00203\,(t_m-32)]\left(1+0.38\frac{e}{P}\right)\text{Log}\frac{P}{P'}$$

$$\text{Log } P'=\text{Log } P-\frac{h}{60{,}600\,[1+0.00203\,(t_m-32)]\left(1+0.38\frac{e}{P}\right)}$$

where t_m is the mean temperature between the surface and the altitude h, t_m is given by the relation

$$t_m=\frac{\text{surface temperature}+\text{temperature at } h \text{ feet}}{2}.$$

The columns headed P of Table II were computed using these formulas.

Example.—Calculate the barometric pressure at 3,000 feet, where the ground pressure is 30.50 inches of mercury, the temperature 80° F. and the relative humidity 75 percent.

Solution.—If the relative humidity were 100 percent the air would be saturated with water vapor at 80° F. and this temperature would be the dew point. Since it actually is only 75 percent saturated, the pressure of water vapor in the air is 75 percent of the saturation pressure. From Table I it is found that $\frac{3}{8}e$ at 80° F. is 0.38 inch of mercury, and the actual vapor pressure of water present in the air is

$$0.38\times0.75=0.285''$$

$$\text{Hence } \frac{\frac{3}{8}e}{P}=\frac{0.285}{30.50}$$

$$t_m-32=\frac{80+70}{2}-32=75-32=43°\text{ F.}$$

The formula for determining the value of P' becomes—

$$\text{Log } P' = \text{Log } P - \frac{3{,}000}{60{,}600\ (1+0.00203\times 43)\ (1+0.285/30.5)}$$
$$=1.439080$$
$$\therefore P' = 27.48''.$$

Section X

PRESSURE HEIGHT (*P. H.*) AND PERCENTAGE OF FULLNESS (*F*)

35. Definition of pressure height.—The term "pressure height" originated in the operation of rigid airships and is the height at which the cells become full of gas or under pressure and is determined by the percentage of fullness (*F*) upon leaving the ground and by atmospheric conditions. The "pressure height" of a nonrigid or semirigid airship is the height at which the ballonets become completely emptied of air and the envelope completely filled with gas, which is also determined by the percentage of gas fullness at the surface and atmospheric conditions.

36. Determination of percentage of fullness, "*F*".—*a.* In rigid airships where the cells can be seen at all times from the keel it is possible, through practice, to estimate very closely the percentage of fullness of each individual gas compartment by studying the conformity and shape of the bottom portion of the cells. It is possible to obtain accurately the percentage of fullness by going to pressure height and obtaining the condition of pressure and temperature at that altitude. It is then easy to get the percentage of fullness for any other condition, or air density, by simple comparison with the determined conditions where the cells were full.

b. In nonrigid airships it is possible to determine approximately the gas content by weighing off. It is also possible to determine the factor "*F*" by flying the airship to pressure height and determining the air density at the altitude reached and comparing it with that at the surface. This will be more fully explained in the succeeding paragraphs.

c. In the operation of helium-inflated airships it is customary to take off with such a value of *F* as will enable the airship to climb to anticipated altitudes without valving gas unless this value of *F* is too low to lift the required load. The F adequate to lift necessary loading is determined by use of the lift formulas.

37. Determination of pressure height, "*P. H.*"—*a.* If the factor "F" is known and the density of the air at the point of starting is known, it is possible to determine the altitude at which the airship will be full of gas (*P. H.*) by determining the altitude at which the airship will reach atmosphere which is of such density as will permit the volume to expand to the total gas capacity of the airship; that is, where F will become 100 percent.

b. The volume of gas in the airship in accordance with the isothermal expansion formula varies directly as $\frac{T}{P}$, which in turn varies inversely as D_a. Hence $\frac{V'}{V}=\frac{F}{100}=\frac{D'_a}{D_a}$ where V' and F are the gas volume and percentage of fullness at the surface and D'_a the air density at *P. H.* Accordingly $D'_a=FD_a$, or the density at *P. H.* equals the surface density multiplied by the percentage of fullness at the surface. Knowing D'_a, the altitude of *P. H.* may be taken from Table II, as illustrated in the following example.

Example.—Given a rigid airship leaving the ground with known volume of 75 percent fullness when the condition on the surface happens to be standard. It is desired to determine what height the airship can reach without loss of gas.

$$\frac{V'}{V}=\frac{75}{100}=\frac{\text{Volume at surface}}{\text{Volume at } P.\ H.}=F.$$

An airship leaving the ground 75 percent full will be full at an altitude where the air density is 75 percent of that at the surface, or

$$D_a \text{ surface} \times F = D'_a \text{ at } P.\ H.$$

D'_a at *P. H.*$=0.0807\times0.75=0.0605=$9,000 feet (approximate).

SECTION XI

MAXIMUM ALTITUDE AND STATIC EFFICIENCY

38. Definition of certain expressions used in altitude problems.—There are certain terms used in altitude and static efficiency problems that should be defined more fully to enable a complete understanding of the succeeding problems. These are defined as follows:

a. The *absolute weight* is the total weight of the airship and its complete load; or the absolute weight equals the gross lift or buoyancy when the airship is in equilibrium plus the weight of the inflating gas.

b. The *dead weight* is the fixed weight of the complete airship with her fixed armament without gas, crew, ballast, fuel, oil, supplies, or bombs. In other words, the dead weight is that part of the absolute weight which is fixed and invariable.

NOTE.—The oil in the crank case of engines and water in the radiators should be considered as part of the fixed or dead weight of the airship.

c. The *load* of the airship is equal to the gross lift and includes the useful load and the dead weight.

d. The *useful load* is that part of the load which is not a fixed part of the airship but which is carried for useful purposes. The useful load includes crew, ballast, fuel, oil, and all supplies.

e. The *disposable load* is that part of the absolute weight which can be disposed of as ballast in case of emergency and usually includes all ballast, bombs, and a part of the fuel, oil, and supplies.

f. The *indisposable load* is that part of the absolute weight which is indisposable, and which includes the dead weight of the airship, the crew, a small reserve of fuel, and any part of the supplies which may be too valuable to dispose of as ballast in case of emergency.

g. The *gross lift* is the total lift of the gas in the airship, or $FV\ (D_a - D_g)$.

h. The *ballonet ceiling* is the maximum altitude to which a pressure airship may ascend and return to the surface under pressure.

i. The *ballast ceiling* is the maximum altitude to which an airship may ascend and return to the surface in equilibrium.

39. Methods of determining static efficiency of airships.—There are two methods that have been used in the past for determining static efficiency of an airship, which is very confusing as each method gives a different result. To be able to determine the performance to be expected from a certain airship with stated static efficiency, it is necessary first to determine which method has been used. A description of both methods follows:

a. The *first method* is the method in which the static efficiency is taken as a percentage of the gross lift when the airship is full of gas and is the ratio of the useful load to the gross lift of the gas.

$$U = \text{static efficiency} = \text{ratio of useful to gross lift}$$
$$= \frac{\text{gross lift} - \text{fixed weights}}{\text{gross lift}}$$
$$= 1 - \frac{\text{fixed weights}}{\text{gross lift}}.$$

Problem No. 1.—After completing a rigid airship of 5,000,000 cubic feet and totaling the weight statements, it is found that the complete airship weighs 135,000 pounds. It is desired to determine her static efficiency when filled with—

(1) Helium lifting 60 pounds per 1,000 cubic feet.
Solution:

$$U = \frac{300{,}000 - 135{,}000}{300{,}000} = \frac{165{,}000}{300{,}000}$$
$$= 0.55 = 55 \text{ percent static efficiency.}$$

(2) Hydrogen lifting 68 pounds per 1,000 cubic feet.
Solution:

$$U = \frac{340{,}000 - 135{,}000}{340{,}000} = \frac{205{,}000}{340{,}000}$$
$$= 0.60 = 60 \text{ percent static efficiency.}$$

NOTE.—Large airships are usually designed for operation with one of the two gases, hydrogen or helium, but seldom for both.

b. The *second method* is the method in which the static efficiency of the airship is considered a percentage of the weight of the air displaced and is the ratio of the useful load to the weight of the air displaced when the airship is full of gas.

$$U' = \text{static efficiency}$$
$$= \frac{\text{useful load with full ship}}{\text{weight of air displaced}}$$
$$= \frac{\text{useful load}}{\text{useful load} + \text{fixed weight} + \text{weight of gas}}$$
$$= 1 - \frac{\text{fixed weight} + \text{weight of gas}}{\text{weight of air displaced}}.$$

Problem No. 2.—Take the same problem as given in *a* above, in which the 5,000,000-cubic-foot airship has a dead fixed weight of 135,000 pounds. It is desired to determine the static efficiency when—

(1) D_a is 0.07800 and D_g is 0.018 (helium).

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Solution.—With helium—

$$U'=1-\left(\frac{\text{dead weight}+VD_g}{VD_a}\right)$$

$$=1-\left(\frac{135{,}000+90{,}000}{390{,}000}\right)=1-\left(\frac{225{,}000}{390{,}000}\right)$$

$$=0.423=42 \text{ percent static efficiency.}$$

(2) D_a is 0.07800 and D_g is 0.010 (hydrogen).
Solution.—With hydrogen—

$$U'=1-\left(\frac{\text{dead weight}+VD_g}{VD_a}\right)$$

$$=1-\left(\frac{135{,}000+50{,}000}{390{,}000}\right)=1-\left(\frac{185{,}000}{390{,}000}\right)$$

$$=0.526=53 \text{ percent static efficiency.}$$

NOTE.—In the remainder of this manual the first method of determining static efficiency will be used.

40. Factors limiting maximum altitude of airships.—*a.* The maximum altitude that a rigid airship can reach under any given atmospheric conditions and still return safely to the surface is determined by one factor only, the disposable load, which is always limited by the static efficiency of the airship.

b. The maximum altitude that a nonrigid or semirigid airship can reach and return safely to earth under pressure and in equilibrium is limited by two factors—the ballonet capacity and the disposable weight. The former is seldom designed to allow a higher ballonet ceiling than the maximum altitude that the disposable weight will allow, as it would not be economical to have a larger ballonet than could be used.

c. If a pressure airship ascends higher than the limit prescribed by the ballonet capacity it does so by valving gas. This gas can not be recalled to maintain pressure and compensate for the contraction consequent to descent. Hence, when the airship has descended a distance approximately equal to its ballonet ceiling it will be unable to descend further without loss of pressure. This is attended by loss of shape, loss of control, and the necessity for free ballooning the airship to a landing, which is a dangerous maneuver.

d. To obviate the possibility of the pilot exceeding the ballonet ceiling airships can be designed so that the ballonet capacity is sufficient to take care of the highest altitude the airship could reach both statically and dynamically. This is unusual, but many airships do include rip panels which allow air to be pumped into the gas cells should necessity require.

e. To insure a margin of safety in landing, the pilot should allow 1,000 feet in altitude. For instance, if the maximum altitude is 10,000 feet the airship should not ascend above 9,000 feet.

f. As an airship descends from ballonet ceiling to the surface the volume of gas varies inversely as the air density. Hence the volume relations at the two altitudes are given by the equation

$$\frac{V'}{V}=\frac{D_a}{D'_a}$$

where D'_a is the air density at ballonet ceiling and V' the volume at that altitude. However, the gas volume at the surface is limited by the ballonet capacity. Hence

$$V=V'(1-B) \text{ where } B \text{ is the ballonet ratio.}$$

Then

$$D'_a=D_a(1-B).$$

Knowing D'_a, the altitude of ballonet ceiling may be taken from Table II by interpolation.

g. When an airship which is full of gas at the surface takes off in equilibrium its lift is given by the equation (neglecting superheat and humitity)—

$$L=VD_a(1-S).$$

At any altitude above the surface the lift is given by the equation

$$L'=VD'_a(1-S).$$

Hence $$L'=L\frac{D'_a}{D_a}. \quad \text{(See fig. 4.)}$$

(1) Where b is the disposable load and L' the lift at ballast ceiling

$$L'=L-b$$

$$\frac{b}{L}=\text{percentage of disposal load}$$

$D'_a=\frac{L'}{L}D_a$ from above. Hence substituting the value at L':

$$D'_a=\left(1-\frac{b}{L}\right)D_a$$

$$=D_a(1-\text{percentage of disposable load}).$$

Ballast ceiling may be found from this formula, using Table II.

(2) When the airship is not full of gas at the take-off, D_a in the above formula is the air density at *P. H.*, as the lift is invariable below *P. H.*

h. As shown in figure 4, the airship leaves the surface 100 percent full. Hence the airship is at *P. H.* all the way up to 9,000 feet, the ballonet ceiling, since *B* is 25 percent. During this time the lift, varying directly as D_a, decreases to 75 percent. The curve of the lift is shown as a straight line, since the air density curve is approximately a straight line up to 9,000 feet. On the descent the volume, varying inversely as D_a, decreases to 75 percent, whereas the lift remains constant because the gas is free to contract.

i. As shown in figure 5, the airship is always below *P. H.*, so the lift is unchanged throughout, while the volume varies between (1–*B*) percent and 100 percent.

j. Figure 6 illustrates the various conditions of an airship rising from the surface 85 percent full with 24 percent ballast. At 5,000 feet due to 15 percent decrease in D_a, the ship reaches *P. H.* Here she drops her bombs and due to her rapid rise assisted by her motors she does not stop at ballast ceiling but continues to 20,000 feet, from which altitude she cannot land in equilibrium.

41. Ballonet ceiling problems.—*a. Problem No. 1.*—An airship is designed with a ballonet ratio (*B*) of 25 percent. The barometric pressure is 30.5 inches and the surface temperature is 50° F.

What is the ballonet ceiling?

Solution:

$$D'_a = D_a(1-B)$$
$$= 0.07920(1-0.25) = 0.07920 \times 0.75$$
$$= 0.05940.$$

Interpolating from Table II, the altitude corresponding to 0.05940 is found to be—

$$h = 9{,}000 \text{ feet} + \left(\frac{0.06000-0.05940}{0.06000-0.05802}\right) 1{,}000 \text{ feet}$$
$$= 9{,}000 + 303$$
$$= 9{,}303 \text{ feet} = \text{ballonet ceiling.}$$

b. Problem No. 2.—An airship is to be designed with a ballonet ceiling of 15,000 feet when the surface temperature is 60° F. and the pressure 30 inches.

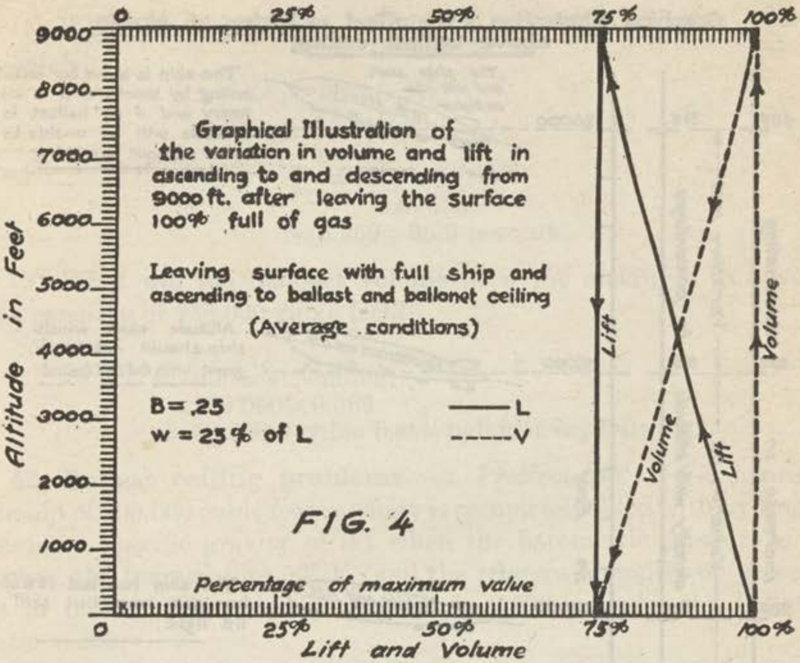

FIG. 4

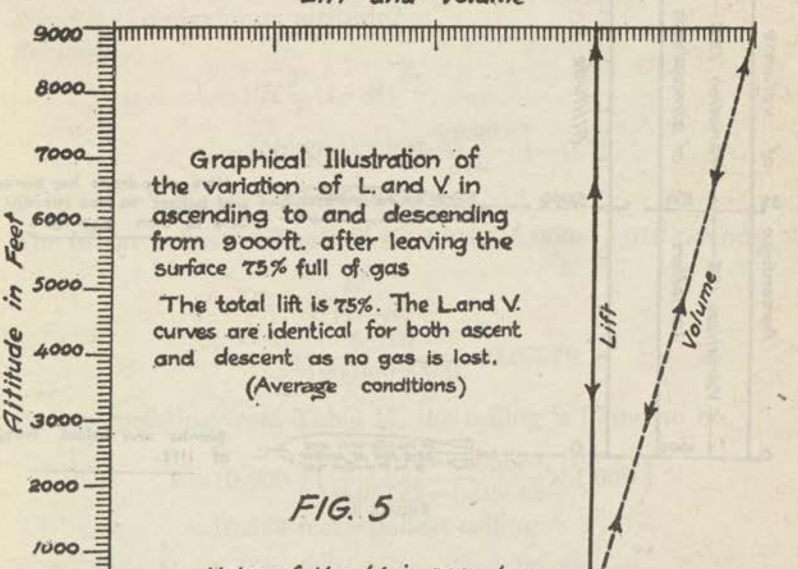

FIG. 5

FIGURES 4 and 5.

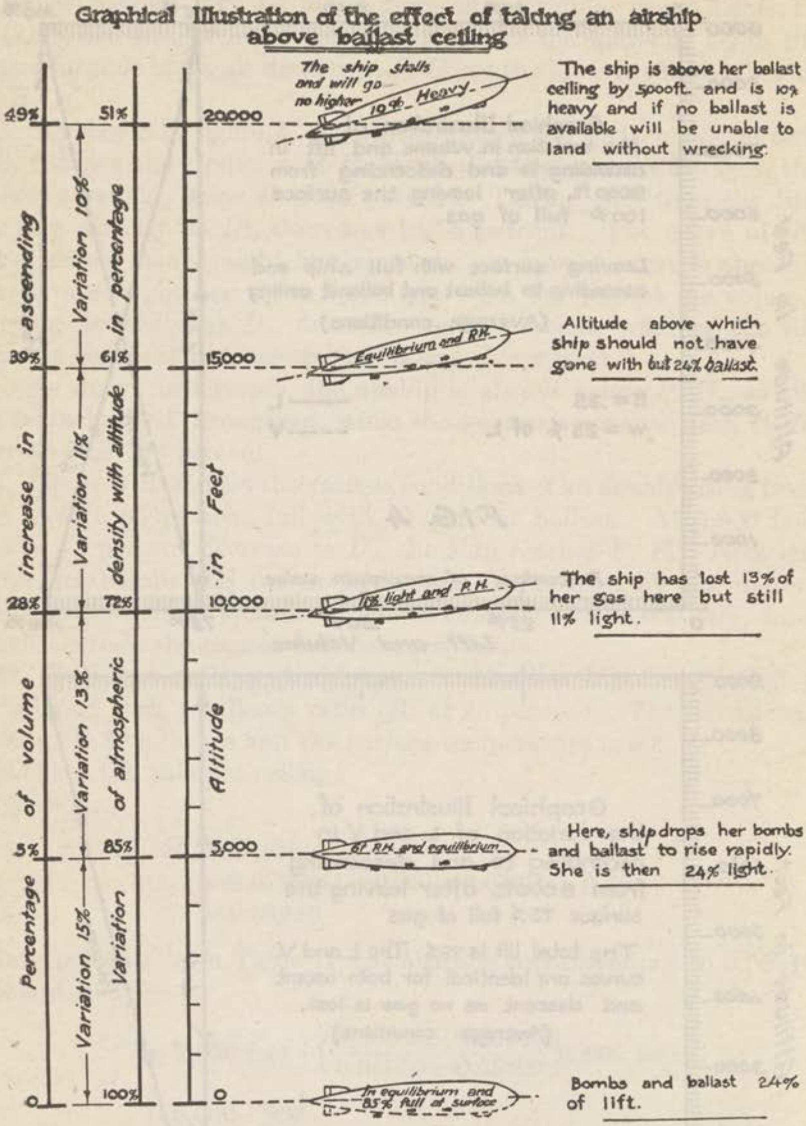
Graphical Illustration of the effect of taking an airship above ballast ceiling
The ship stalls and will go no higher
10% Heavy
The ship is above her ballast ceiling by 5000ft. and is 10% heavy and if no ballast is available will be unable to land without wrecking.
49%
51%
20,000
Equilibrium and R.H.
Altitude above which ship should not have gone with but 24% ballast.
39%
61%
15000
11% light and R.H.
The ship has lost 13% of her gas here but still 11% light.
28%
72%
10,000
R.H. and equilibrium
Here, ship drops her bombs and ballast to rise rapidly. She is then 24% light.
5%
85%
5,000
In equilibrium and 85% full at surface
Bombs and ballast 24% of lift.
0
100%
0
Percentage of volume increase in ascending
Variation 15%
Variation 13%
Variation 11%
Variation 10%
Variation of atmospheric density with altitude in percentage
Altitude in Feet

FIGURE 6.

(1) What will the ballonet ratio be?

Solution:

$$D'_a = D_a(1-B)$$

$$B = \frac{D_a - D'_a}{D_a}$$

$$= \frac{0.07625-0.04808}{0.07625}$$

$$= 0.369 = 36.9 \text{ percent.}$$

(2) What will the ballonet volume be if the airship is to have a gas capacity of 250,000 cubic feet?

Solution:

$$v = \text{ballonet volume}$$

$$= 250{,}000 \times 0.369$$

$$= 92{,}250.0 \text{ cubic feet} = \text{ballonet capacity.}$$

42. Ballast ceiling problems.—*a. Problem No. 1.*—A nonrigid airship of 100,000 cubic feet capacity is completely filled with hydrogen having a specific gravity of 0.1 when the barometric pressure is 30 inches, the temperature 50° F., and the relative humidity 60 percent, as in tables. The available ballast is 2,000 pounds; the ballonet ratio 0.333.

What is the maximum altitude?

Solution:

$$L = VK\frac{P}{T}(1-S)$$

$$= 100{,}000 \times 1.327\ \frac{29.92}{510}\ (1-0.1)$$

$$= 7{,}010 \text{ pounds.}$$

The lift at ballast ceiling will be 7,010−2,000=5,010 pounds, then

$$D'_a = \frac{L'}{V(1-S)}$$

$$= \frac{5{,}010}{100{,}000 \times 0.9} = 0.05570.$$

By interpolating from Table II, the ceiling is found to be

$$h = 10{,}000 + \left(\frac{0.05727-0.05570}{0.05727-0.05545} \times 1{,}000\right)$$

$$= 10.863 \text{ feet} = \text{ballast ceiling.}$$

b. Problem No. 2.—A rigid airship of 5,000,000 cubic feet capacity has a disposable load of 100,000 pounds when fully inflated with helium gas of 0.2 specific gravity. The surface temperature is 60° F., barometric pressure 30 inches, and average relative humidity 60 percent.

What is the ballast ceiling?
Solution:

$$L=5{,}000{,}000\times 1.327\ \frac{29.89}{520}\ (1-0.2)$$
$$=305{,}000 \text{ pounds}$$
$$L'=305{,}000-100{,}000=205{,}000$$
$$\frac{L'}{L}=\frac{D'_a}{D_a}$$
$$D'_a=0.07625\times\frac{205{,}000}{305{,}000}$$
$$=0.05125$$

Interpolating from Table II, the altitude of D'_a is found to be

$$h=12{,}000+\left(\frac{0.05295-0.05125}{0.05295-0.05120}\times 1{,}000\right)$$
$$=12{,}971 \text{ feet}=\text{ballast ceiling.}$$

SECTION XII

ADIABATIC INFLUENCES UPON EQUILIBRIUM OF AIRSHIPS AND BALLOONS

43. Adiabatic expansion and compression of gases.—*a*. Adiabatic expansion of compression takes place when air or other gases are expanded or compressed without a transfer of heat energy to or from them.

b. The law that the volume of gas varies inversely as the pressure maintained assumes that the temperature is kept constant, otherwise temperature change must be considered. For instance, if the pressure is halved the volume will be doubled, provided sufficient heat energy is supplied to the expanding mass to keep the temperature constant. But according to the definition of adiabatic expansion no heat energy can be added to or lost from the expanding mass of gas. This prevents the gas temperature from remaining constant and prevents the volume expanding to the full amount which it would reach under constant temperature.

(1) For instance, for a pressure reduction of one-half, by the isothermal law—

$$\frac{P}{P'}=\frac{V'}{V} \text{ or } \frac{\text{Original pressure}}{\text{Final pressure}}=\frac{\text{Final volume}}{\text{Original volume}}=\frac{2}{1}$$

(2) Under the restrictions imposed upon adiabatic expansion—

$$\frac{P}{P'}=\left(\frac{V'}{V}\right)^{1.41}$$

(3) In general, gases under adiabatic expansion or compression follow the equation—

$$PV^c=\text{constant}$$

where $c=C_p/C_v$, the ratio of the specific heat of the gas at constant pressure to its specific heat at constant volume. These ratios have been determined as follows:

$1.41=C_p/C_v$ for air
$1.41=C_p/C_v$ for hydrogen
$1.66=C_p/C_v$ for helium

c. The following formulas give the exponents for all adiabatic variations in P, T, and V for air, which are sufficiently correct for other gases as the true adiabatic condition cannot be realized in airships and balloons.

$$P'=P\left(\frac{V}{V'}\right)^{1.41}$$

$$V'=V\left(\frac{P}{P'}\right)^{0.71}$$

$$T'=T\left(\frac{V}{V'}\right)^{0.41}$$

$$P'=P\left(\frac{T'}{T}\right)^{3.44}$$

$$V'=V\left(\frac{T}{T'}\right)^{2.44}$$

$$T'=T\left(\frac{P'}{P}\right)^{0.29}$$

where P=initial pressure in inches of mercury.
V=initial volume in cubic feet.
T=initial absolute temperature in degrees F.
P'=Pressure in inches of mercury after compression or expansion.
V'=Volume in cubic feet after compression or expansion.
T'=Absolute temperature in degrees F. after compression or expansion.

d. If P is 30 inches and T is 500° at the surface, at 1,000 feet P' will be 29 inches and T' 496.6°, approximately.

(1) If then 1,000 cubic feet of air rises isothermally—

$$V'=\frac{30\times1{,}000\times496.6}{29\times500}=1{,}027.5 \text{ cubic feet}$$

(2) If T' had remained at 500°—

$$V'=\frac{30\times1{,}000}{29}=1{,}034 \text{ cubic feet}$$

(3) If the air had risen adiabatically—

$$V'^{\,1.41}=\frac{30}{29}1{,}000^{1.41}$$

$$V'=1{,}024 \text{ cubic feet}$$

(4) The loss in volume between the isothermal and adiabatic expansions is due to the temperature relation between the normal gradient and the adiabatic gradient, since the pressure change is the same in both cases. Hence, the temperature after adiabatic expansion equals $\frac{1{,}024\times500}{1{,}034}$ or 495°, a decrease of 5° in 1,000 feet.

44. Adiabatic vertical atmospheric temperature gradient.—*a*. Variations of the inner gas temperature are produced by the ascending or descending motions of an airship or balloon in partial accordance with adiabatic laws. Were it not for conduction through the envelope, the expansion would follow the adiabatic laws exactly. When an airship or balloon ascends and the gas is free to expand within the container without a loss or gain in heat energy, the decrease of gas temperature is approximately 1° F. per 200 feet of ascent, but the outer or atmospheric temperature decrease averages about 1° F. per 300 feet of ascent. The inverse effect is of course experienced in descending. A condition of adiabatic superheating thus arises which is negative in ascending and positive in descending and has a marked effect on the conditions of equilibrium after a rapid ascent or descent.

b. While the changes of the inner gas temperature closely follow the adiabatic rate where rapid ascents and descents are made, there are three conditions of the vertical atmospheric temperature gradient to be considered, stable, unstable, and neutral. These are discussed in detail in paragraph 45.

45. Equilibrium of atmosphere.—*a*. *Neutral*.—The atmosphere is said to be in neutral equilibrium when the vertical temperature gradient is the same as that of the adiabatic rate of temperature change. So long as this condition exists the temperature of a mass of air rising dynamically would always be the same as the temperature of the surrounding atmosphere, provided it be initially the same at the plane of starting, and consequently there would be no tendency to either increase or decrease the initial velocity.

b. Stable.—(1) The atmosphere is in stable equilibrium when its vertical temperature gradient is less than that of the adiabatic, that is, the rate of temperature decrease with altitude is less than the adiabatic rate. When this condition exists a mass of air, rising dynamically, is cooled at the adiabatic rate, which, being greater than the existing vertical temperature gradient, causes the rising column of air to cool at a greater rate than the surrounding atmosphere. Due to the greater density of the colder rising mass of air than that of the warmer surrounding air, there is set up an increasing downward force, which, as soon as the initial dynamic force is overcome, will cause the rising mass of cooler air to descend and heat at the adiabatic rate until its temperature and density become the same as that of the surrounding air.

(2) At night the earth radiates its heat to space and cools the air near the earth by conduction. This produces a temperature inversion and consequently a condition of very stable equilibrium. At night, also, there is little unequal heating of the earth's surface such as is experienced during the sunlight hours. Hence there are few convectional currents and these are rapidly halted by the extreme stability of the atmosphere. These facts explain the so-called nocturnal stability.

c. Unstable.—The air is in unstable equilibrium when the vertical temperature gradient is greater than that of the adiabatic, that is, when the rate of decrease in temperature with increase in altitude is greater than the adiabatic rate. Though this condition seldom exists, it is possible under extreme conditions of excessive heating near the surface of the earth. A mass of air rising dynamically and cooling at the adiabatic rate would always have a higher temperature than the surrounding atmosphere. The rising air due to its greater temperature and lesser density would continue to rise of its own accord after the initial dynamic force had ceased to exist and as long as the unstable condition existed.

46. Effect of conditions of atmospheric vertical temperature gradient upon static equilibrium of airships and balloons.—Eliminating from the present discussion the sometimes enormous effect of superheating of the gas from the sun's rays, the following conclusions are established.

a. Neutral.—When the vertical temperature gradient is the same as the adiabatic the temperature of the gas in an airship or balloon remains the same as that of the surrounding air. Therefore during an ascent the lift remains constant below *P. H.* An airship or balloon starting statically light and not under power would rise to *P. H.* with constant lift and due to its momentum would continue until it had exceeded its altitude of equilibrium sufficiently to overcome the momentum. At this point it would be heavy and would return to the surface with constant heaviness.

b. Stable.—When the vertical temperature gradient is less than the adiabatic the gas in the ascending envelope is subjected to negative superheat, which causes a temporary reduction in lift. Therefore the airship or balloon in rising statically strikes a point below its altitude of equilibrium at which its momentum is arrested by a temporary heaviness. It starts to descend, but almost immediately due to conduction its negative superheat is partially lost and it rises again, gradually oscillating into its altitude of equilibrium.

c. Unstable.—When the vertical temperature gradient is greater than the adiabatic the gas in the ascending envelope is subjected to positive superheat with resultant increased lift. Hence the rising airship will overshoot its altitude of momentum even more than in the case of neutral equilibrium.

47. Ballonet ceiling adiabatic.—*Example.*—Compute the ballonet ceiling (adiabatic) of an airship whose ballonet capacity is 31.35 percent of the total capacity on a day when the ground pressure is 30 inches of mercury and the ground temperature is 50° F.

Let V=volume of gas in airship on ground.
P=pressure on ground.
V' and P'=the volume and pressure at the ceiling.
Then V'=100 per cent.
V=100−31.35 or 68.65 per cent.

$$P=P'\left(\frac{V'}{V}\right)^{1.4}$$

$$P'=\frac{30\text{ inches}}{\left(\frac{100.00}{68.65}\right)^{1.4}}$$

$$=\frac{30\text{ inches}}{(1.457)^{1.4}}$$

$$=\frac{30\text{ inches}}{1.693}$$

$$=17.72\text{ inches.}$$

Ballonet ceiling (adiabatic) = 13,740 feet. (See Table II.)

a. In this case the isothermal ballonet ceiling is 12,180 feet, or about 1,500 feet lower than the adiabatic ceiling. Just how much of the excess could be used and the airship returned to the surface under pressure is a mooted question, but experiments with superheat indicate that one-third would be available if the ascent were rapid. However, the airship should not remain at altitudes above the isothermal ceiling because air and gas temperatures quickly equalize.

b. The reverse effect obtains in a rapid dive, the gas being expanded by adiabatic superheat, assisting the pilot to land an airship which has overshot its ballonet ceiling or is statically heavy.

SECTION XIII

RULES FOR SHORT-CUT METHODS OF COMPUTATION

48. Rules used in short-cut methods of calculation and for approximations in aerostatic problems.

a. Rule No. 1.—Lift of an airship varies as the volume if all other conditions affecting lift remain constant.

b. Rule No. 2.—Lift of a given volume of gas increases if barometric pressure increases and lift decreases if pressure decreases.

c. Rule No. 3.—Lift of a given volume of gas will decrease if atmospheric temperature increases and will increase if temperature is decreased.

d. Rule No. 4.—The higher the atmospheric humidity the less the lift.

e. Rule No. 5.—There is no change in equilibrium due to a change in barometric pressure when the gas is free to expand.

f. Rule No. 6.—Where air and gas temperature change an equal amount there is no change in equilibrium if the gas is free to expand.

g. Rule No. 7.—An airship in equilibrium at any altitude will be in equilibrium at the surface, providing no weight is lost or gained and the superheat value is not changed in descending.

h. Rule No. 8.—An airship rising from the surface in equilibrium will be in equilibrium at any altitude below pressure height if no weight is lost or gained and the superheat value does not change.

i. Rule No. 9.—Barometric pressure will decrease approximately 1 inch for every 1,000 feet of ascent in the lower atmosphere.

j. Rule No. 10.—Atmospheric temperature will decrease approximately 1° F. for every 300 feet ascent, or 3⅓° for every 1,000 feet ascent.

k. Rule No. 11.—Gas volume is changed 1 percent for every 5° F. change in gas temperature.

l. Rule No. 12.—Gas density is changed 1 percent for every 5° F. change in gas temperature.

m. Rule No. 13.—One percent change in gas density or specific gravity foɪ hydrogen changes the lift one-tenth percent when at pressure height.

n. Rule No. 14.—One percent change in gas density or specific gravity for helium changes the lift two-tenths percent when at pressure height.

o. Rule No. 15.—At pressure height the lift will change only 1 percent for 20° F. superheat with helium and 1 percent for 45° F. superheat with hydrogen. This shows the danger in going from maximum daytime superheat conditions to zero superheat value at night if not properly understood and counteracted.

p. Rule No. 16.—Lift is changed 1 percent for every 5° F. change in superheat in flight if the gas is free to expand.

q. Rule No. 17.—(1) 5° F. superheat will lower the pressure height 360 feet at altitudes below 7,000 feet.

(2) 5° F. superheat will lower the pressure height 400 feet at altitudes above 7,000 feet.

r. Rule No. 18.—In ascending under average atmospheric conditions the volume will increase 1 percent for every 360 feet of ascent in rising to 7,000 feet and increase 1 percent for every 400 feet above 7,000 feet.

s. Rule No. 19.—In going above pressure height lift is reduced 1 percent for every 360 feet below 7,000 feet and 1 percent for every 400 feet when above 7,000 feet.

t. Rule No. 20.—One percent of the original mass of gas is lost in going 360 feet over pressure height when below 7,000 feet and 1 percent is lost for every 400 feet ascent above 7,000 feet altitude.

u. Rule No. 21.—If, when full of gas, 1 percent of the lift is thrown over as ballast, equilibrium will be reached when 1 percent of the gas has been valved.

v. Rule No. 22.—Loss of lift due to presence of water vapor in the atmosphere may be determined from the following table for short-cut or approximate calculations. First determine the lift for dry air from the lift chart, then correct for humidity by multiplying the lift by the value $1-0.38\ e/P$. Where the relative humidity is known, the value given for 0.38 e/P at saturation should be multiplied by the relative humidity value before subtracting from 1.

Air temperature	Loss in lift at saturation	Actual value of 0.38 e/P at saturation	L×(1−0.38 e/P) at saturation
0° F.	1/20 percent of 1 percent	0.0005	Lift × 0.9995
20° F.	1/10 percent of 1 percent	.0013	Lift × .9987
32° F.	1/5 percent of 1 percent	.0022	Lift × .9978
50° F.	1/2 percent of 1 percent	.0045	Lift × .9955
70° F.	1 percent less than dry air	.0093	Lift × .9907
90° F.	1.8 percent less than dry air	.0178	Lift × .9820
100° F.	2.5 percent less than dry air	.0250	Lift × .9750

SECTION XIV

AEROSTATIC FORMULAS, SYMBOLS, GRAPHS, AND TABLES

49. Formulas used in aerostatic computation.—*a*. The formulas that are used most often in practical aerostatic problems are listed for convenience as follows:

(1) *For determining air and gas density.*

$$D_a = 1.327\frac{P-0.38e}{T}$$

$$^{D}\text{helium} = 0.183\frac{P-0.38e}{T}$$

$$^{D}\text{hydrogen} = 0.092\frac{P-0.38e}{T}$$

(2) *For determining lift.*

LF No. 1: Lift when air and gas temperatures are the same:

$$L = \frac{FVK(P-0.38e)}{T}(1-S).$$

LF No. 2: Lift with superheat:

$$L = \frac{FVK(P-0.38e)(T_g-T_aS)}{T_a \times T_g}.$$

LF No. 3: Lift with changed superheat in flight:

$$L = \frac{FVK(P-0.38e)(T_g - T_aS)}{T_a \times T_g} + \frac{FVK(P-0.38e)\Delta T'_g}{T_a \times T_g}.$$

LF No. 4: Lift, taking into consideration the effects of superpressure:

$$L = \frac{FVK[(P-0.38e) - P'S]}{T}.$$

(3) *For determining altitude of any given pressure.*

$$h = 60{,}600\,[1 + 0.00203(t_m - 32)](1 + 0.38e/P)\,\text{Log}\,\frac{P}{P'}$$

(4) *For determining pressure at any given altitude.*

$$\text{Log}\,P' = \text{Log}\,P - \frac{h}{60{,}600\,[1 + 0.00203(t_m - 32)](1 + 0.38e/P)}$$

(5) *For determining temperature of any altitude.*

$$t' = t - \frac{h}{300}\ \text{degrees F.}$$

(6) *Isothermal expansion.*

$$\frac{VP}{T} = \frac{V'P'}{T'}.$$

(7) *Adiabatic expansion.*

$$P' = P\left(\frac{V}{V'}\right)^{1.41}$$

$$V' = V\left(\frac{P}{P'}\right)^{0.71}$$

$$T' = T\left(\frac{V}{V'}\right)^{0.41}$$

$$P' = P\left(\frac{T'}{T}\right)^{3.44}$$

$$V' = V\left(\frac{T}{T'}\right)^{2.44}$$

$$T' = T\left(\frac{P'}{P}\right)^{0.29}$$

(8) *For determining the percentage of fullness "F."*

$$F=\frac{L}{L'}=\frac{\text{Lift required for total load}}{\text{Total lift if airship were full of gas}}.$$

(9) *For determining pressure height with any given percentage of fullness at the surface.*

$$D'_a=D_a\times F.$$

To determine altitude of D'_a see Table II.

(10) *For determining static efficiency of an airship.*

$$U=\text{static efficiency}=\text{ratio of useful to gross lift}$$
$$=\frac{\text{useful lift}}{\text{gross lift}}.$$

(11) *For determining weight of ballast or expendable load necessary to reach a given altitude.*

$$\text{Ballast}=L\frac{D_a-D'_a}{D_a}. \quad \text{(Use Table II.)}$$

For determining the ballast ceiling:

$$D'_a=D_a\frac{L-b}{L}. \quad \text{(Use Table II.)}$$

(12) *For determining ballonet ratio required to reach any altitude.*

$$B=1-\frac{D'_a}{D_a}. \quad \text{(Use Table II.)}$$

For determining the ballonet ceiling:

$$D'_a=D_a(1-B). \quad \text{(Use Table II.)}$$

b. The following constants are used frequently in computation:

(1) *Standard density.*—(*a*) Air=0.08072 pound per cubic foot.

(*b*) Hydrogen=0.00562 pound per cubic foot.

(*c*) Helium=0.0111 pound per cubic foot.

(*d*) Illuminating gas=0.0323 pound per cubic foot.

(2) *Specific gravity.*—(*a*) Dry air=1.

(*b*) Pure hydrogen=0.069.

(*c*) Pure helium=0.138.

(*d*) Illuminating gas=0.4 (approximate).

(3) $K=1.327$=density constant for air.

(4) $C'_g=0.092$=density constant for hydrogen.

(5) $C_g=0.183$=density constant for helium.

50. Explanation of graphs in figures 7, 8, 9, and 10.—*a*. Figure 7 is a graphical chart for determining the lift of helium gas per 1,000 cubic feet. With given pressure, temperature, and specific gravity (or purity), begin at the given barometric pressure and move pointer horizontally to the right until the line of the given temperature is intercepted; then move pointer vertically down until the given specific gravity line is intercepted; then move pointer horizontally to the right and read the lift per 1,000 cubic feet at the right margin.

b. Figure 8 is a graphical chart for determining the lift of hydrogen gas per 1,000 cubic feet and is read in the same manner as the helium chart (fig. 7).

c. Figure 9 is a graphical chart showing the values of barometric pressure and the decrease in atmospheric temperature between the surface and 36,000 feet altitude under average conditions. The approximate pressure at any given altitude may be read directly from the chart. To determine the temperature at any given altitude, add the decrease indicated on the chart to the surface temperature algebraically.

d. Figure 10 is a graphical chart showing the variation in atmospheric density with altitude under average conditions. From this density curve it is possible to determine the changes in gas volume with changes in altitude, also changes in lift when ascending from the surface with the airship full of gas.

e. Figures 11 and 12 show the conversion of specific gravity to purity, and vice versa, for helium and hydrogen. The charts are self-explanatory.

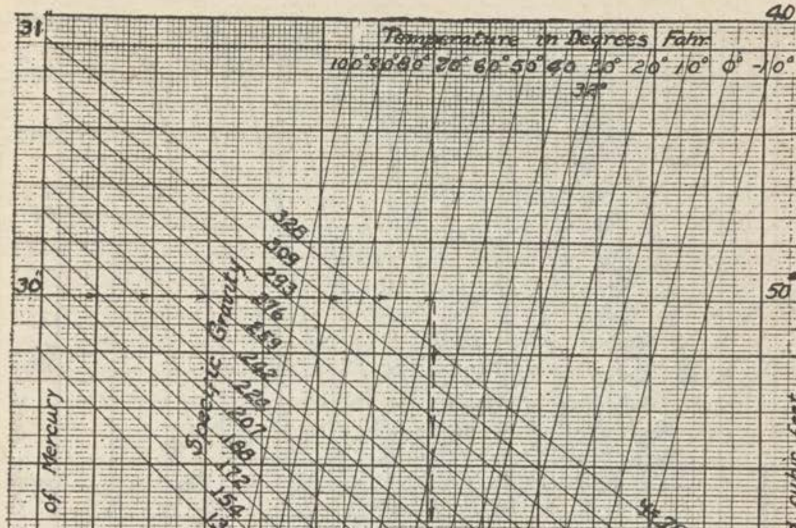

FIGURE 7.—Lift of helium in dry air per 1,000 cubit feet.

Example: From pressure 30″, to temperature 60°, to purity 96. to lift equals 63.6 pounds.

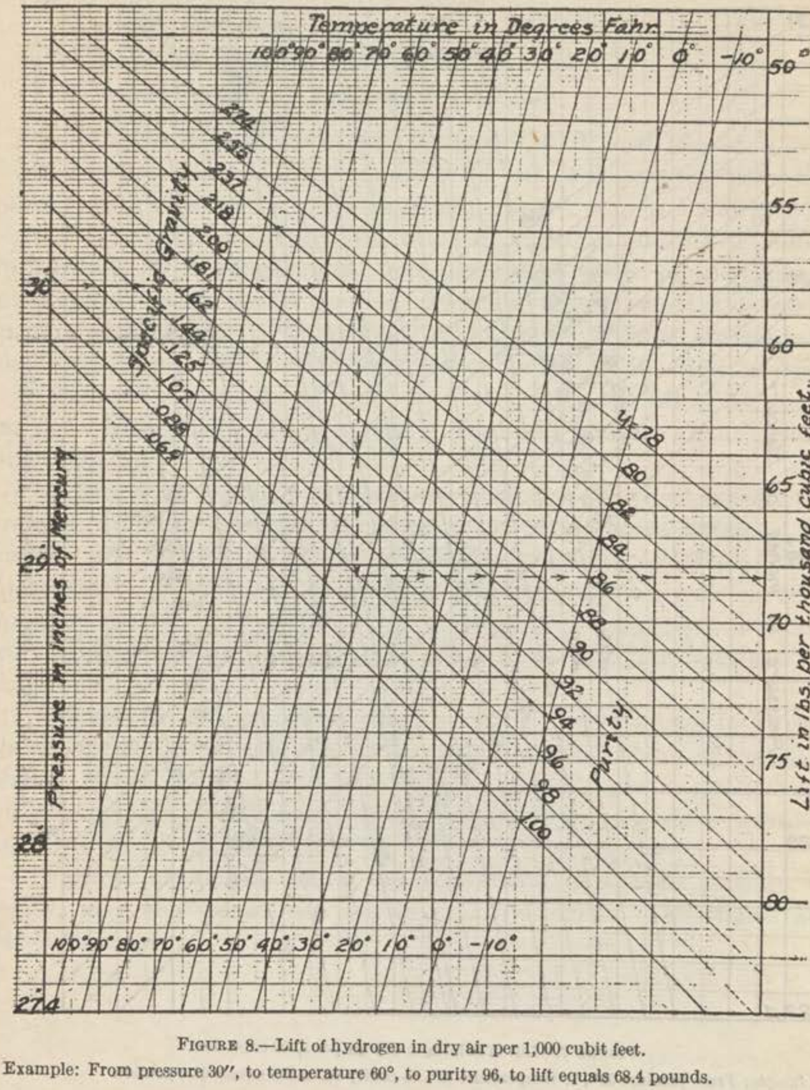

FIGURE 8.—Lift of hydrogen in dry air per 1,000 cubit feet.
Example: From pressure 30″, to temperature 60°, to purity 96, to lift equals 68.4 pounds.

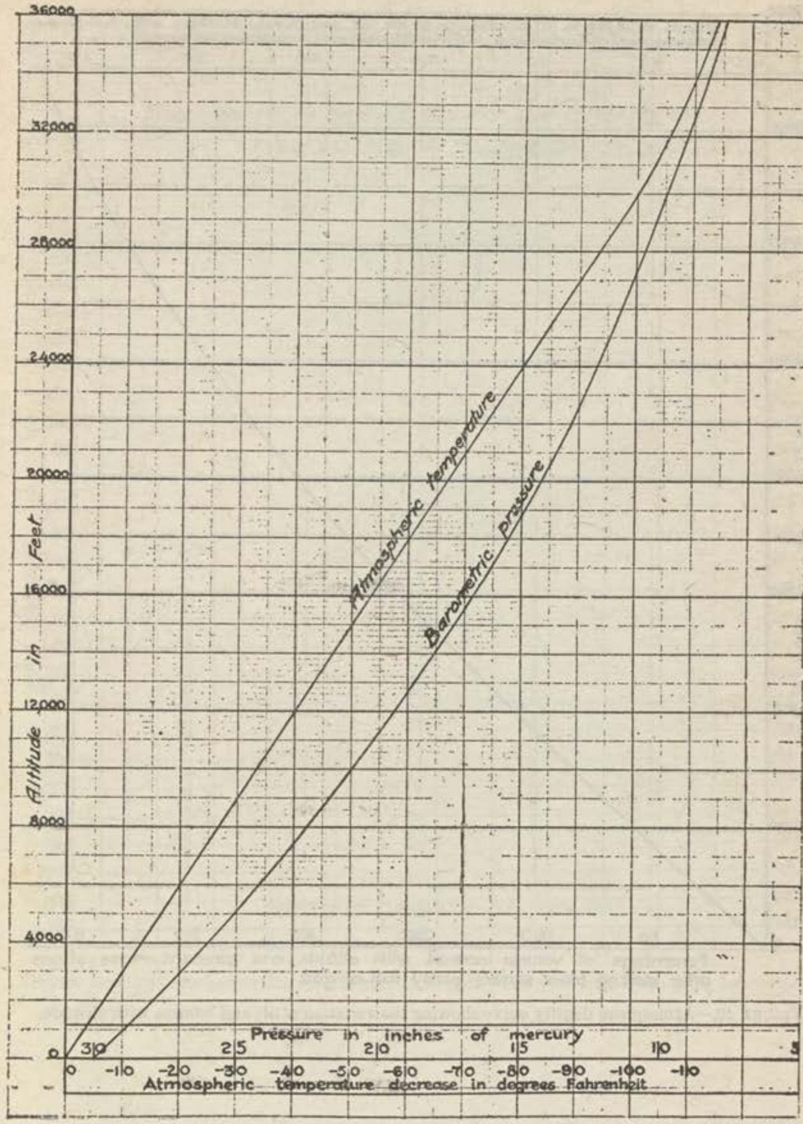

FIGURE 9.—Pressure and temperature decrease with altitude (average conditions).

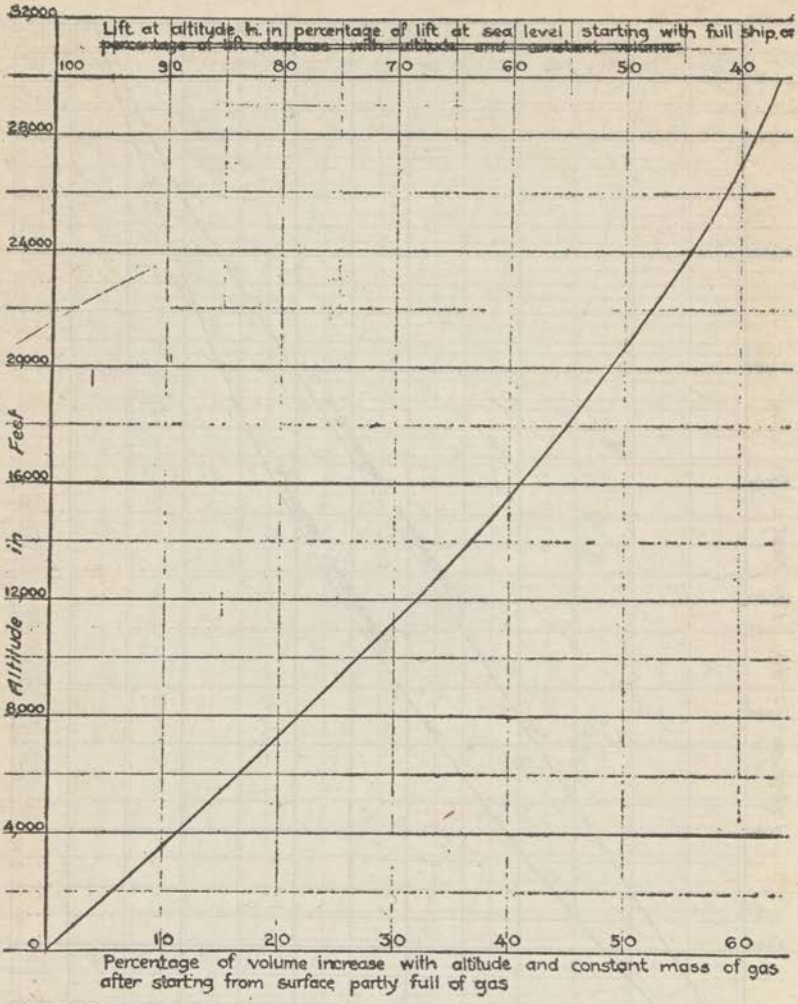

FIGURE 10.—Atmosphere density curve showing the variation of lift and volume with altitude.

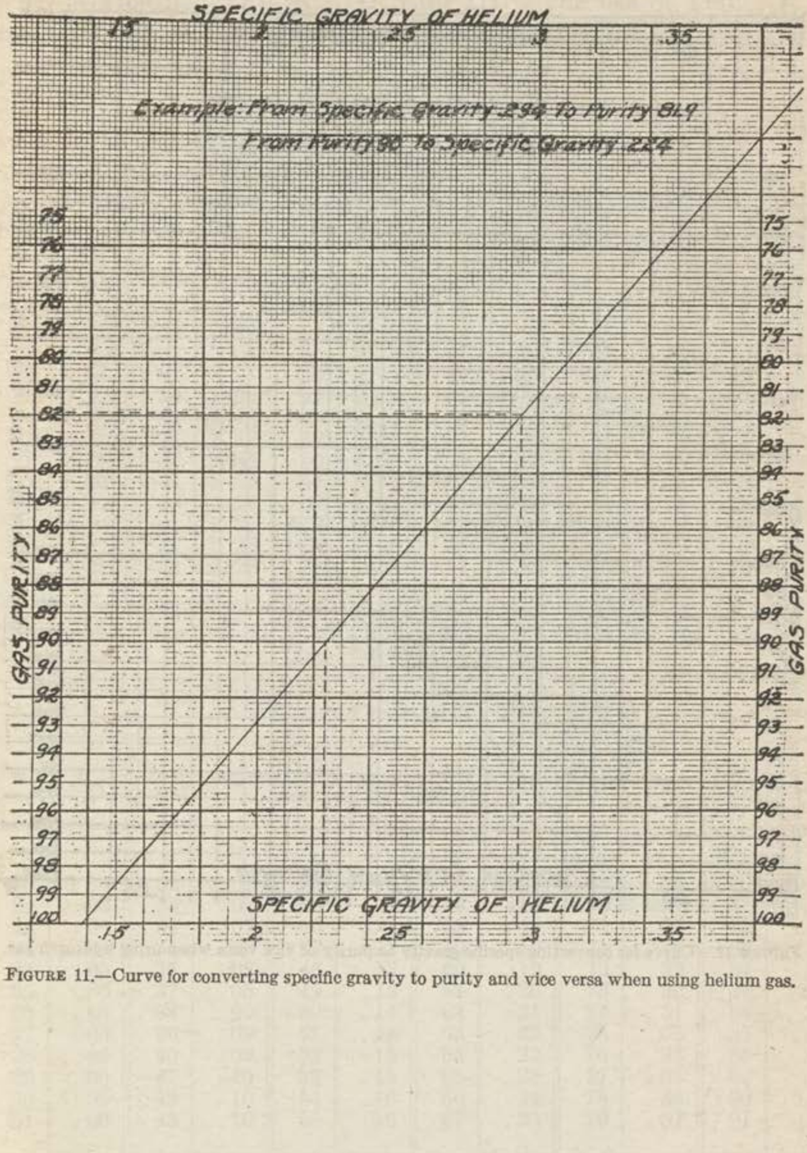

FIGURE 11.—Curve for converting specific gravity to purity and vice versa when using helium gas.

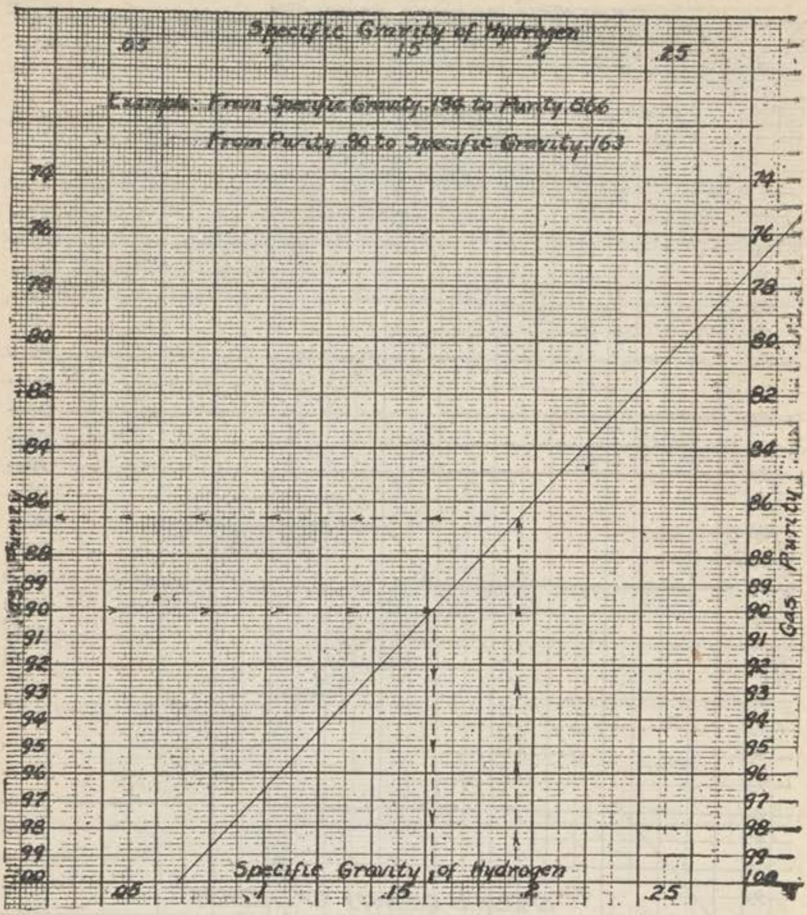

FIGURE 12.—Curve for converting specific gravity to purity or vice versa when using hydrogen gas.

51. Aerostatic Tables I, II, and III.—The use of Tables I, II, and III has been explained in previous paragraphs.

TABLE IA.—*Humidity*

GLAISHER'S FACTOR

Dry bulb	Glaisher's factor	Dry bulb	Glaisher's factor	Dry bulb	Glaisher's factor	Dry bulb	Glaisher's factor	Dry bulb	Glaisher's factor	Dry bulb	Glaisher's factor
° F.		° F.		° F.		° F.		° F.		° F.	
20	8. 14	32	3. 32	44	2. 18	56	1. 94	68	1. 79	80	1. 68
21	7. 88	33	3. 01	45	2. 16	57	1. 92	69	1. 78	81	1. 68
22	7. 60	34	2. 77	46	2. 14	58	1. 90	70	1. 77	82	1. 67
23	7. 28	35	2. 60	47	2. 12	59	1. 89	71	1. 76	83	1. 67
24	6. 92	36	2. 50	48	2. 10	60	1. 88	72	1. 75	84	1. 66
25	6. 53	37	2. 42	49	2. 08	61	1. 87	73	1. 74	85	1. 65
26	6. 08	38	2. 36	50	2. 06	62	1. 86	74	1. 73	86	1. 65
27	5. 61	39	2. 32	51	2. 04	63	1. 85	75	1. 72	87	1. 64
28	5. 12	40	2. 29	52	2. 02	64	1. 83	76	1. 71	88	1. 64
29	4. 63	41	2. 26	53	2. 00	65	1. 82	77	2. 70	89	1. 63
30	4. 15	42	2. 23	54	1. 98	66	1. 81	78	1. 69	90	1. 63
31	3. 70	43	2. 20	55	1. 96	67	1. 80	79	1. 69	91	1. 62

Dew point = dry bulb − [G × (dry bulb − wet bulb)] where G is the Glaisher's factor taken from above

⅜ vapor pressure, or 0.38*e*

Dew point	⅜*e*	Dew point	⅜*e*	Dew point	⅜*e*	Dew point	⅜*e*	Dew point	⅜*e*	Dew point	⅜*e*
° F.		° F.		° F.		° F.		° F.		° F.	
20	0. 04	32	0. 07	44	0. 11	56	0. 17	68	0. 26	80	0. 38
21	. 04	33	. 07	45	. 11	57	. 17	69	. 27	81	. 40
22	. 04	34	. 07	46	. 12	58	. 18	70	. 27	82	. 41
23	. 04	35	. 08	47	. 12	59	. 19	71	. 28	83	. 42
24	. 05	36	. 08	48	. 13	60	. 19	72	. 29	84	. 44
25	. 05	37	. 08	49	. 13	61	. 20	73	. 30	85	. 45
26	. 05	38	. 09	50	. 14	62	. 21	74	. 31	86	. 46
27	. 05	39	. 09	51	. 14	63	. 22	75	. 33	87	. 48
28	. 06	40	. 09	52	. 15	64	. 22	76	. 34	88	. 50
29	. 06	41	. 10	53	. 15	65	. 23	77	. 35	89	. 51
30	. 06	42	. 10	54	. 16	66	. 24	78	. 36	90	. 53
31	. 06	43	. 10	55	. 16	67	. 25	79	. 37	91	. 55

TABLE IB.—*Relative humidity, percent, Fahrenheit scale*

Dry thermometers	Difference between dry and wet thermometers																
	0.5°	1°	2°	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°
20°	92	85	70	41	13	---	---	---	---	---	---	---	---	---	---	---	---
30°	94	89	78	57	36	17	---	---	---	---	---	---	---	---	---	---	---
32°	95	90	79	59	40	21	3	---	---	---	---	---	---	---	---	---	---
38°	96	92	83	67	50	34	18	3	---	---	---	---	---	---	---	---	---
45°	96	92	85	71	58	44	32	19	7	---	---	---	---	---	---	---	---
50°	97	93	87	74	61	50	38	27	16	6	---	---	---	---	---	---	---
55°	97	94	88	76	65	54	43	34	24	15	6	---	---	---	---	---	---
60°	97	94	89	78	68	58	48	39	30	22	14	6	---	---	---	---	---
65°	97	95	90	80	70	61	52	44	35	28	20	13	6	---	---	---	---
68°	98	95	90	81	71	63	54	46	38	31	24	17	10	4	---	---	---
70°	98	95	90	81	72	64	55	48	40	33	26	19	13	7	1	---	---
75°	98	95	91	82	74	66	58	51	44	37	31	24	19	13	7	2	---
80°	98	96	92	83	75	68	61	54	47	41	35	29	23	18	13	8	3
90°	----	96	92	85	78	71	65	59	53	47	41	36	32	26	22	17	13
95°	----	96	93	86	79	73	66	60	55	49	44	39	35	30	24	20	17
100°	----	96	93	86	80	73	68	62	56	51	46	41	37	33	28	24	21
105°	----	97	93	87	81	75	69	63	58	53	48	43	40	36	32	28	24
110°	----	97	93	87	81	75	70	65	60	55	50	46	42	38	34	30	26
120°	----	97	94	88	82	77	72	67	62	58	53	49	45	41	38	34	31

Table IIA.—*Surface barometric pressure, 29 inches*

h	460°			470°			480°			h
Feet	D_a	P	$t°$	D_a	P	$t°$	D_a	P	$t°$	Feet
Ground	0. 08365	29. 00	0. 00	0. 08185	29. 00	10. 00	0. 08012	29. 00	20. 00	Ground.
1,000	. 08090	27. 84	−3. 33	. 07919	27. 86	6. 66	. 07756	27. 88	16. 66	1,000.
2,000	. 07830	26. 75	−6. 66	. 07667	26. 78	3. 33	. 07510	26. 81	13. 33	2,000.
3,000	. 07564	25. 65	−10. 00	. 07414	25. 70	0. 00	. 07267	25. 75	10. 00	3,000.
4,000	. 07308	24. 60	−13. 33	. 07167	24. 67	−3. 33	. 07035	24. 75	6. 66	4,000.
5,000	. 07057	23. 58	−16. 66	. 06932	23. 68	−6. 66	. 06808	23. 78	3. 33	5,000.
6,000	. 06816	22. 60	−20. 00	. 06700	22. 72	−10. 00	. 06589	22. 84	0. 00	6,000.
7,000	. 06579	21. 65	−23. 33	. 06471	21. 78	−13. 33	. 06365	21. 91	−3. 33	7,000.
8,000	. 06354	20. 75	−26. 66	. 06253	20. 89	−16. 66	. 06156	21. 03	−6. 66	8,000.
9,000	. 06132	19. 87	−30. 00	. 06038	20. 02	−20. 00	. 05948	20. 17	−10. 00	9,000.
10,000	. 05915	19. 02	−33. 33	. 05832	19. 19	−23. 33	. 05752	19. 36	−13. 33	10,000.
11,000	. 05711	18. 22	−36. 66	. 05635	18. 40	−26. 66	. 05558	18. 57	−16. 66	11,000.
12,000	. 05507	17. 43	−40. 00	. 05435	17. 61	−30. 00	. 05368	17. 80	−20. 00	12,000.
13,000	. 05306	16. 66	−43. 33	. 05244	16. 86	−33. 33	. 05181	17. 05	−23. 33	13,000.
14,000	. 05114	15. 93	−46. 66	. 05056	16. 13	−36. 66	. 05004	16. 34	−26. 66	14,000.
15,000	. 04926	15. 22	−50. 00	. 04875	15. 43	−40. 00	. 04827	15. 64	−30. 00	15,000.
16,000	. 04738	14. 52	−53. 33	. 04694	14. 74	−43. 33	. 04652	14. 96	−33. 33	16,000.
17,000	. 04563	13. 87	−56. 66	. 04527	14. 10	−46. 66	. 04489	14. 32	−36. 66	17,000.
18,000	. 04396	13. 25	−60. 00	. 04363	13. 48	−50. 00	. 04329	13. 70	−40. 00	18,000.
19,000	. 04232	12. 65	−63. 33	. 04203	12. 88	−53. 33	. 04175	13. 11	−43. 33	19,000.
20,000	. 04074	12. 08	−66. 66	. 04050	12. 31	−56. 66	. 04026	12. 54	−46. 66	20,000.

TABLE IIA.—*Surface barometric pressure, 29 inches*—Continued

h	490°			500°			510°			h
Feet	D_a	P	t°	D_a	P	t°	D_a	P	t°	Feet
Ground	0. 07844	29. 00	30. 00	0. 07682	29. 00	40. 00	0. 07524	29. 00	50. 00	Ground.
1,000	. 07593	27. 89	26. 66	. 07444	27. 91	36. 66	. 07296	27. 93	46. 66	1,000.
2,000	. 07355	26. 84	23. 33	. 07216	26. 87	33. 33	. 07075	26. 90	43. 33	2,000.
3,000	. 07117	25. 80	20. 00	. 06991	25. 85	30. 00	. 06859	25. 90	40. 00	3,000.
4,000	. 06892	24. 82	16. 66	. 06781	24. 90	26. 66	. 06658	24. 97	36. 66	4,000.
5,000	. 06673	23. 88	13. 33	. 06576	23. 98	23. 33	. 06466	24. 08	33. 33	5,000.
6,000	. 06461	22. 96	10. 00	. 06374	23. 08	20. 00	. 06283	23. 20	30. 00	6,000.
7,000	. 06241	22. 04	6. 66	. 06166	22. 17	16. 66	. 06072	22. 30	26. 66	7,000.
8,000	. 06036	21. 18	3. 33	. 05972	21. 32	13. 33	. 05884	21. 46	23. 33	8,000.
9,000	. 05865	20. 33	0. 00	. 05780	20. 48	10. 00	. 05697	20. 63	20. 00	9,000.
10,000	. 05671	19. 52	−3. 33	. 05596	19. 69	6. 66	. 05523	19. 86	16. 66	10,000.
11,000	. 05489	18. 75	−6. 66	. 05416	18. 92	3. 33	. 05350	19. 10	13. 33	11,000.
12,000	. 05302	17. 98	−10. 00	. 05242	18. 17	0. 00	. 05177	18. 35	10. 00	12,000.
13,000	. 05125	17. 25	−13. 33	. 05068	17. 44	−3. 33	. 05013	17. 64	6. 66	13,000.
14,000	. 04951	16. 54	−16. 66	. 04903	16. 75	−6. 66	. 04852	16. 95	3. 33	14,000.
15,000	. 04783	15. 86	−20. 00	. 04739	16. 07	−10. 00	. 04696	16. 28	0. 00	15,000.
16,000	. 04616	15. 19	−23. 33	. 04685	15. 41	−13. 33	. 04542	15. 63	−3. 33	16,000.
17,000	. 04456	14. 55	−26. 66	. 04421	14. 77	−16. 66	. 04391	15. 00	−6. 66	17,000.
18,000	. 04299	13. 93	−30. 00	. 04268	14. 15	−20. 00	. 04240	14. 38	−10. 00	18,000.
19,000	. 04149	13. 34	−33. 33	. 04124	13. 57	−23. 33	. 04100	13. 80	−13. 33	19,000.
20,000	. 04006	12. 78	−36. 66	. 03984	13. 01	−26. 66	. 03963	13. 24	−16. 66	20,000.

h	515°			520°			530°			h
Feet	D_a	P	$t°$	D_a	P	$t°$	D_a	P	$t°$	Feet
Ground	0. 07447	29. 00	55. 00	0. 07373	29. 00	60. 00	0. 07219	29. 00	70. 00	Ground.
1,000	. 07226	27. 95	51. 66	. 07154	27. 96	56. 66	. 07012	27. 98	66. 66	1,000.
2,000	. 07007	26. 92	48. 33	. 06940	26. 94	53. 33	. 06811	26. 99	63. 33	2,000.
3,000	. 06825	25. 94	45. 00	. 06736	25. 97	50. 00	. 06613	26. 03	60. 00	3,000.
4,000	. 06600	25. 01	41. 66	. 06540	25. 05	46. 66	. 06427	25. 13	56. 66	4,000.
5,000	. 06412	24. 13	38. 33	. 06356	24. 17	43. 33	. 06248	24. 26	53. 33	5,000.
6,000	. 06221	23. 25	35. 00	. 06196	23. 30	40. 00	. 06067	23. 40	50. 00	6,000.
7,000	. 06024	22. 36	31. 66	. 05969	22. 42	36. 66	. 05882	22. 53	46. 66	7 000.
8,000	. 05825	21. 52	28. 33	. 05796	21. 59	33. 33	. 05710	21. 72	43. 33	,000.
9,000	. 05655	20. 70	25. 00	. 05615	20. 77	20. 00	. 05537	20. 92	40. 00	9,000.
10,000	. 05486	19. 94	21. 66	. 05447	20. 01	26. 66	. 05373	20. 16	36. 66	10,000.
11,000	. 05315	19. 18	18. 33	. 05253	19. 26	23. 33	. 05224	19. 42	33. 33	11,000.
12,000	. 05144	18. 43	15. 00	. 05113	18. 52	20. 00	. 05025	18. 69	30. 00	12,000.
13,000	. 04984	17. 73	11. 66	. 04955	17. 82	16. 66	. 04899	18. 00	26. 66	13,000.
14,000	. 04825	17. 04	8. 33	. 04798	17. 13	13. 33	. 04745	17. 31	23. 33	14,000.
15,000	. 04669	16. 37	5. 00	. 04646	16. 47	10. 00	. 04599	16. 66	20. 00	15,000.
16,000	. 04516	15. 72	1. 66	. 04495	15. 82	6. 66	. 04454	16. 02	16. 66	16,000.
17,000	. 04343	15. 10	−1. 67	. 04350	15. 20	3. 33	. 04313	15. 40	13. 33	17,000.
18,000	. 04223	14. 48	−5. 00	. 04206	14. 58	0. 00	. 04172	14. 79	10. 00	18,000.
19,000	. 04084	13. 90	−8. 33	. 04071	14. 01	−3. 33	. 04040	14. 22	6. 66	19,000.
20,000	. 03947	13. 34	−11. 66	. 03937	13. 45	−6. 66	. 03912	13. 67	3. 33	20,000.

TABLE IIA.—*Surface barometric pressure, 29 inches*—Continued

h	540°			550°			560°			*h*
Feet	D_a	*P*	$t°$	D_a	*P*	$t°$	D_a	*P*	$t°$	Feet
Ground	0. 07069	29. 00	80. 00	0. 06919	29. 00	90. 00	0. 06768	29. 00	100. 00	Ground.
1,000	. 06874	28. 01	76. 66	. 06733	28. 03	86. 66	. 06594	28. 06	96. 66	1,000.
2,000	. 06679	27. 03	73. 33	. 06550	27. 08	83. 33	. 06434	27. 12	93. 33	2,000.
3,000	. 06468	26. 10	70. 00	. 06371	26. 16	80. 00	. 06251	26. 23	90. 00	3,000.
4,000	. 06314	25. 21	66. 66	. 06201	25. 29	76. 66	. 06112	25. 37	86. 66	4,000.
5,000	. 06141	24. 35	63. 33	. 06034	24. 44	73. 33	. 05928	24. 53	83. 33	5,000.
6,000	. 05967	23. 50	60. 00	. 05867	23. 60	70. 00	. 05767	23. 70	80. 00	6,000.
7,000	. 05792	22. 65	56. 66	. 05700	22. 76	66. 66	. 05605	22. 88	76. 66	7,000.
8,000	. 05622	21. 84	53. 33	. 05538	21. 97	63. 33	. 05453	22. 10	73. 33	8,000.
9,000	. 05458	21. 06	50. 00	. 05383	21. 21	60. 00	. 05304	21. 35	70. 00	9,000.
10,000	. 05303	20. 32	46. 66	. 05230	20. 47	56. 66	. 05158	20. 62	66. 66	10,000.
11,000	. 05145	19. 58	43. 33	. 05079	19. 74	53. 33	. 05013	19. 90	63. 33	11,000.
12,000	. 04990	18. 86	40. 00	. 04930	19. 03	50. 00	. 04869	19. 20	60. 00	12,000.
13,000	. 04847	18. 19	36. 66	. 04792	18. 37	46. 66	. 04737	18. 55	56. 66	13,000.
14,000	. 04696	17. 50	33. 33	. 04645	17. 68	43. 33	. 04593	17. 86	53. 33	14,000.
15,000	. 04553	16. 85	30. 00	. 04508	17. 04	40. 00	. 04462	17. 23	50. 00	15,000.
16,000	. 04411	16. 21	26. 66	. 04371	16. 41	36. 66	. 04328	16. 60	46. 66	16,000.
17,000	. 04276	15. 60	23. 33	. 04239	15. 80	33. 33	. 04202	16. 00	43. 33	17,000.
18,000	. 04138	14. 99	20. 00	. 04106	15. 20	30. 00	. 04072	15. 40	40. 00	18,000.
19,000	. 04009	14. 42	16. 66	. 03980	14. 63	26. 66	. 03952	14. 84	36. 66	19,000.
20,000	. 03977	13. 88	13. 33	. 03864	14. 10	23. 33	. 03838	14. 31	33. 33	20,000.

TABLE IIB.—*Surface barometic pressure, 29.5 inches*

h	460°			470°			480°			h
Feet	D_a	P	t°	D_a	P	t°	D_a	P	t°	Feet
Ground	0. 08510	29. 50	0. 00	0. 08326	29. 50	10. 00	0. 08150	29. 50	20. 00	Ground.
1,000	. 08229	28. 32	−3. 33	. 08055	28. 34	6. 66	. 07892	28. 37	16. 66	1,000.
2,000	. 07953	27. 17	−6. 66	. 07793	27. 22	3. 33	. 07639	27. 27	13. 33	2,000.
3,000	. 07682	26. 05	−10. 00	. 07535	26. 12	0. 00	. 07392	26. 19	10. 00	3,000.
4,000	. 07427	25. 00	−13. 33	. 07291	25. 09	−3. 33	. 07157	25. 18	6. 66	4,000.
5,000	. 07181	23. 99	−16. 66	. 07052	24. 09	−6. 66	. 06925	24. 19	3. 33	5,000.
6,000	. 06937	23. 00	−20. 00	. 06814	23. 11	−10. 00	. 06698	23. 22	0. 00	6,000.
7,000	. 06686	22. 00	−23. 33	. 06575	22. 13	−13. 33	. 06471	22. 27	−3. 33	7,000.
8,000	. 06461	21. 10	−26. 66	. 06358	21. 24	−16. 66	. 06258	21. 38	−6. 66	8,000.
9,000	. 06234	20. 20	−30. 00	. 06140	20. 36	−20. 00	. 06051	20. 52	−10. 00	9,000.
10,000	. 06018	19. 35	−33. 33	. 05932	19. 52	−23. 33	. 05850	19. 69	−13. 33	10,000.
11,000	. 05815	18. 55	−36. 66	. 05736	18. 73	−26. 66	. 05657	18. 90	−16. 66	11,000.
12,000	. 05605	17. 74	−40. 00	. 05533	17. 93	−30. 00	. 05462	18. 11	−20. 00	12,000.
13,000	. 05398	16. 95	−43. 33	. 05334	17. 15	−33. 33	. 05273	17. 35	−23. 33	13,000.
14,000	. 05201	16. 20	−46. 66	. 05144	16. 41	−36. 66	. 05089	16. 62	−26. 66	14,000.
15,000	. 05007	15. 47	−50. 00	. 04957	15. 69	−40. 00	. 04910	15. 91	−30. 00	15,000.
16,000	. 04820	14. 77	−53. 33	. 04777	15. 00	−43. 33	. 04734	15. 22	−33. 33	16,000.
17,000	. 04639	14. 10	−56. 66	. 04601	14. 33	−46. 66	. 04564	14. 56	−36. 66	17,000.
18,000	. 04469	13. 47	−60. 00	. 04447	13. 74	−50. 00	. 04404	13. 94	−40. 00	18,000.
19,000	. 04305	12. 87	−63. 33	. 04278	13. 11	−53. 33	. 04248	13. 34	−43. 33	19,000.
20,000	. 04143	12. 28	−66. 66	. 04119	12. 52	−56. 66	. 04097	12. 76	−46. 66	20,000.

TABLE IIB.—*Surface barometric pressure, 29.5 inches*—Continued

h	490°			500°			510°			h
Feet	D_a	P	$t°$	D_a	P	$t°$	D_a	P	$t°$	Feet
Ground	0.07979	29.50	30.00	0.07814	29.50	40.00	0.07655	29.50	50.00	Ground.
1,000	.07732	28.39	26.66	.07580	28.42	36.66	.07430	28.44	46.66	1,000.
2,000	.07493	27.32	23.33	.07351	27.37	33.33	.07212	27.42	43.33	2,000.
3,000	.07253	26.26	20.00	.07120	26.33	30.00	.06992	26.40	40.00	3,000.
4,000	.07029	25.27	16.66	.06907	25.36	26.66	.06786	25.45	36.66	4,000.
5,000	.06805	24.29	13.33	.06689	24.39	23.33	.06576	24.49	33.33	5,000.
6,000	.06586	23.34	10.00	.06477	23.45	20.00	.06370	23.56	30.00	6,000.
7,000	.06366	22.40	6.66	.06269	22.54	16.66	.06172	22.67	26.66	7,000.
8,000	.06160	21.52	3.33	.06068	21.66	13.33	.05978	21.80	23.33	8,000.
9,000	.05966	20.68	0.00	.05880	20.84	10.00	.05799	21.00	20.00	9,000.
10,000	.05774	19.87	−3.33	.05695	20.04	6.66	.05621	20.21	16.66	10,000.
11,000	.05585	19.08	−6.66	.05510	19.25	3.33	.05442	19.43	13.33	11,000.
12,000	.05396	18.30	−10.00	.05331	18.48	0.00	.05267	18.67	10.00	12,000.
13,000	.05211	17.54	−13.33	.05155	17.74	−3.33	.05098	17.94	6.66	13,000.
14.000	.05035	16.82	−16.66	.04985	17.03	−6.66	.04935	17.24	3.33	14,000.
15,000	.04862	16.12	−20.00	.04818	16.34	−10.00	.04777	16.56	0.00	15,000.
16,000	.04695	15.45	−23.33	.04655	15.67	−13.33	.04620	15.90	−3.33	16,000.
17,000	.04532	14.80	−26.66	.04499	15.03	−16.66	.04467	15.26	−6.66	17,000.
18,000	.04373	14.17	−30.00	.04346	14.41	−20.00	.04317	14.64	−10.00	18,000.
19,000	.04224	13.58	−33.33	.04197	13.81	−23.33	.04174	14.05	−13.33	19,000.
20,000	.04072	12.99	−36.66	.04051	13.23	−26.66	.04032	13.47	−16.66	20,000.

h	515°			520°			530°			h
Feet	D_a	P	t^o	D_a	P	t^o	D_a	P	t^o	Feet
Ground	0. 07576	29. 50	55. 00	0. 07497	29. 50	60. 00	0. 07344	29. 50	70. 00	Ground.
1,000	. 07358	28. 45	51. 67	. 07282	28. 46	56. 66	. 07138	28. 48	66. 66	1,000.
2,000	. 07144	27. 44	48. 33	. 07078	27. 46	53. 33	. 06940	27. 50	63. 33	2,000.
3,000	. 06932	26. 43	45. 00	. 06864	26. 46	50. 00	. 06740	26. 53	60. 00	3,000.
4,000	. 06724	25. 48	41. 67	. 06665	25. 52	46. 66	. 06554	25. 60	56. 66	4,000.
5,000	. 06518	24. 53	38. 33	. 06464	24. 58	43. 33	. 06355	24. 67	53. 33	5,000.
6,000	. 06316	23. 61	35. 00	. 06267	23. 67	40. 00	. 06166	23. 78	50. 00	6,000.
7,000	. 06124	22. 73	31. 67	. 06076	22. 79	36. 66	. 05981	22. 91	46. 66	7,000.
8,000	. 05938	21. 87	28. 33	. 05892	21. 94	33. 33	. 05802	22. 07	43. 33	8,000.
9,000	. 05757	21. 07	25. 00	. 05704	21. 14	30. 00	. 05633	21. 28	40. 00	9,000.
10,000	. 05581	20. 28	21. 67	. 05545	20. 37	26. 66	. 05469	20. 52	36. 66	10,000.
11,000	. 05407	19. 51	18. 33	. 05372	19. 59	23. 33	. 05304	19. 76	33. 33	11,000.
12,000	. 05236	18. 76	15. 00	. 05203	18. 84	20. 00	. 05138	19. 01	30. 00	12,000.
13,000	. 05068	18. 03	11. 67	. 05039	18. 12	16. 66	. 04981	18. 30	26. 66	13,000.
14,000	. 04909	17. 34	8. 33	. 04884	17. 43	13. 33	. 04830	17. 62	23. 33	14,000.
15,000	. 04751	16. 66	5. 00	. 04726	16. 75	10. 00	. 04680	16. 95	20. 00	15,000.
16,000	. 04596	16. 00	1. 67	. 04575	16. 10	6. 66	. 04532	16. 30	16. 66	16,000.
17,000	. 04449	15. 37	−1. 67	. 04431	15. 47	3. 33	. 04391	15. 68	13. 33	17,000.
18,000	. 04203	14. 75	−5. 00	. 04284	14. 85	0. 00	. 04248	15. 06	10. 00	18,000.
19,000	. 04157	14. 15	−8. 33	. 04144	14. 26	−3. 33	. 04112	14. 47	6. 66	19,000.
20,000	. 04012	13. 58	−11. 67	. 04007	13. 69	−6. 66	. 03978	13. 90	3. 33	20,000.

TABLE IIB.—*Surface barometric pressure, 29.5 inches*—Continued

h	540°			550°			560°			h
Feet	D_a	P	t°	D_a	P	t°	D_a	P	t°	Feet
Ground	0. 07193	29. 50	80. 00	0. 07040	29. 50	90. 00	0. 06887	29. 50	100. 00	Ground.
1,000	. 06996	28. 50	76. 66	. 06845	28. 52	86. 66	. 06713	28. 54	96. 66	1,000.
2,000	. 06808	27. 55	73. 33	. 06670	27. 59	83. 33	. 06541	27. 63	93. 33	2,000.
3,000	. 06615	26. 59	70. 00	. 06494	26. 66	80. 00	. 06369	26. 72	90. 00	3,000.
4,000	. 06430	25. 67	66. 66	. 06315	25. 75	76. 66	. 06199	25. 82	86. 66	4,000.
5,000	. 06248	24. 77	63. 33	. 06140	24. 86	73. 33	. 06031	24. 95	83. 33	5,000.
6,000	. 06064	23. 88	60. 00	. 05965	23. 99	70. 00	. 05865	24. 10	80. 00	6,000.
7,000	. 05890	23. 04	56. 66	. 05795	23. 16	66. 66	. 05704	23. 28	76. 66	7,000.
8,000	. 05718	22. 21	53. 33	. 05632	22. 34	63. 33	. 05547	22. 48	73. 33	8,000.
9,000	. 05553	21. 42	50. 00	. 05472	21. 56	60. 00	. 05391	21. 70	70. 00	9,000.
10,000	. 05397	20. 68	46. 66	. 05323	20. 83	56. 66	. 05267	20. 99	66. 66	10,000.
11,000	. 05235	19. 92	43. 33	. 05170	20. 09	53. 33	. 05115	20. 25	63. 33	11,000.
12,000	. 05078	19. 19	40. 00	. 05016	19. 36	50. 00	. 04965	19. 53	60. 00	12,000.
13,000	. 04924	18. 48	36. 66	. 04868	18. 66	46. 66	. 04828	18. 84	56. 66	13,000.
14,000	. 04779	17. 81	33. 33	. 04726	17. 99	43. 33	. 04685	18. 18	53. 33	14,000.
15,000	. 04632	17. 14	30. 00	. 04587	17. 34	40. 00	. 04545	17. 53	50. 00	15,000.
16,000	. 04490	16. 50	26. 66	. 04449	16. 70	36. 66	. 04410	16. 90	46. 66	16,000.
17,000	. 04352	15. 88	23. 33	. 04313	16. 09	33. 33	. 04277	16. 30	43. 33	17,000.
18,000	. 04212	15. 26	20. 00	. 04179	15. 47	30. 00	. 04147	15. 68	40. 00	18,000.
19,000	. 04081	14. 68	16. 66	. 04051	14. 89	26. 66	. 04021	15. 10	36. 66	19,000.
20,000	. 03954	14. 12	13. 33	. 03927	14. 33	23. 33	. 03902	14. 55	33. 33	20,000.

TABLE IIC.—*Surface barometric pressure, 30 inches*

h	460°			470°			480°			h
Feet	D_a	P	$t°$	D_a	P	$t°$	D_a	P	$t°$	Feet
Ground	0. 08654	30. 00	−0. 00	0. 08467	30. 00	10. 00	0. 08288	30. 00	20. 00	Ground.
1,000	. 08369	28. 80	−3. 33	. 08195	28. 83	6. 66	. 08020	28. 83	16. 66	1,000.
2,000	. 08079	27. 60	−6. 66	. 07928	27. 69	3. 33	. 07768	27. 71	13. 33	2,000.
3,000	. 07829	26. 55	−10. 00	. 07665	26. 57	0. 00	. 07513	26. 62	10. 00	3,000.
4,000	. 07555	25. 43	−13. 33	. 07413	25. 51	−3. 33	. 07274	25. 59	6. 66	4,000.
5,000	. 07309	24. 42	−16. 66	. 07166	24. 48	−6. 66	. 07037	24. 58	3. 33	5,000.
6,000	. 07066	23. 43	−20. 00	. 06927	23. 49	−10. 00	. 06802	23. 58	0. 00	6,000.
7,000	. 06810	22. 41	−23. 33	. 06690	22. 52	−13. 33	. 06590	22. 67	−3. 33	7,000.
8,000	. 06584	21. 50	−26. 66	. 06468	21. 61	−16. 66	. 06370	21. 76	−6. 66	8,000.
9,000	. 06363	20. 62	−30. 00	. 06249	20. 72	−20. 00	. 06163	20. 90	−10. 00	9,000.
10,000	. 06130	19. 70	−33. 33	. 06035	19. 86	−23. 33	. 05957	20. 05	−13. 33	10,000.
11,000	. 05909	18. 85	−36. 66	. 05834	19. 05	−26. 66	. 05756	19. 23	−16. 66	11,000.
12,000	. 05694	18. 02	−40. 00	. 05635	18. 26	−30. 00	. 05561	18. 44	−20. 00	12,000.
13,000	. 05478	17. 20	−43. 33	. 05443	17. 50	−33. 33	. 05370	17. 67	−23. 33	13,000.
14,000	. 05297	16. 50	−46. 66	. 05235	16. 70	−36. 66	. 05184	16. 93	−26. 66	14,000.
15,000	. 05114	15. 80	−50. 00	. 05052	15. 99	−40. 00	. 05006	16. 22	−30. 00	15,000.
16,000	. 04921	15. 08	−53. 33	. 04866	15. 28	−43. 33	. 04830	15. 53	−33. 33	16,000.
17,000	. 04731	14. 38	−56. 66	. 04694	14. 62	−46. 66	. 04661	14. 87	−36. 66	17,000.
18,000	. 04552	13. 72	−60. 00	. 04525	13. 98	−50. 00	. 04495	14. 23	−40. 00	18,000.
19,000	. 04379	13. 09	−63. 33	. 04360	13. 36	−53. 33	. 04437	13. 61	−43. 33	19,000.
20,000	. 04214	12. 49	−66. 66	. 04192	12. 74	−56. 66	. 04181	13. 03	−46. 66	20,000.

TABLE IIC.—*Surface barometric pressure, 30 inches*—Continued

h	490°			500°			510°			n
Feet	D_a	P	$t°$	D_a	P	$t°$	D_a	P	$t°$	Feet
Ground	0. 08114	30. 00	30. 00	0. 07946	30. 00	40. 00	0. 07788	30. 00	50. 00	Ground.
1,000	. 07858	28. 85	26. 66	. 07703	28. 88	36. 66	. 07550	28. 90	46. 66	1,000.
2,000	. 07598	27. 71	23. 33	. 07470	27. 82	33. 33	. 07332	27. 87	43. 33	2,000.
3,000	. 07373	26. 69	20. 00	. 07247	26. 80	30. 00	. 07110	26. 85	40. 00	3,000.
4,000	. 07143	25. 68	16. 66	. 07027	25. 80	26. 66	. 06893	25. 85	36. 66	4,000.
5,000	. 06919	24. 70	13. 33	. 06801	24. 80	23. 33	. 06687	24. 90	33. 33	5,000.
6,000	. 06703	23. 75	10. 00	. 06582	23. 83	20. 00	. 06481	23. 97	30. 00	6,000.
7,000	. 06486	22. 82	6. 66	. 06381	22. 94	16. 66	. 06282	23. 07	26. 66	7,000.
8,000	. 06275	21. 92	3. 33	. 06185	22. 08	13. 33	. 06086	22. 20	23. 33	8,000.
9,000	. 06078	21. 07	0. 00	. 05986	21. 21	10. 00	. 05911	21. 40	20. 00	9,000.
10,000	. 05875	20. 22	−3. 33	. 05801	20. 41	6. 66	. 05727	20. 60	16. 66	10,000.
11,000	. 05679	19. 40	−6. 66	. 05605	19. 58	3. 33	. 05545	19. 80	13. 33	11,000.
12,000	. 05491	18. 62	−10. 00	. 05423	18. 80	0. 00	. 05370	19. 00	10. 00	12,000.
13,000	. 05309	17. 87	−13. 33	. 05248	18. 06	−3. 33	. 05187	18. 25	6. 66	13,000.
14,000	. 05133	17. 15	−16. 66	. 05073	17. 35	−6. 66	. 05018	17. 53	3. 33	14,000.
15,000	. 04955	16. 43	−20. 00	. 04910	16. 65	−10. 00	. 04858	16. 84	0. 00	15,000.
16,000	. 04786	15. 75	−23. 33	. 04736	15. 94	−13. 33	. 04699	16. 17	−3. 33	16,000.
17,000	. 04617	15. 11	−26. 66	. 04580	15. 30	−16. 66	. 04546	15. 53	−6. 66	17,000.
18,000	. 04465	14. 47	−30. 00	. 04427	14. 68	−20. 00	. 04394	14. 90	−10. 00	18,000.
19,000	. 04308	13. 85	−33. 33	. 04282	14. 09	−23. 33	. 04248	14. 30	−13. 33	19,000.
20,000	. 04160	13. 27	−36. 66	. 04143	13. 53	−26. 66	. 04110	13. 73	−16. 66	20,000.

h	515°			520°			530°			h
Feet	D_a	P	$t°$	D_a	P	$t°$	D_a	P	$t°$	Feet
Ground	0. 07722	30. 00	55. 00	0. 07625	30. 00	60. 00	0. 07469	30. 00	70. 00	Ground.
1,000	. 07477	28. 92	51. 67	. 07403	28. 93	56. 66	. 07256	28. 95	66. 66	1,000.
2,000	. 07255	27. 87	48. 33	. 07191	27. 91	53. 33	. 07051	27. 97	63. 33	2,000.
3,000	. 07045	26. 88	45. 00	. 06980	26. 91	50. 00	. 06845	26. 94	60. 00	3,000.
4,000	. 06832	25. 89	41. 67	. 06772	25. 93	46. 66	. 06645	25. 98	56. 66	4,000.
5,000	. 06643	25. 00	38. 33	. 06572	24. 99	43. 33	. 06483	25. 10	53. 33	5,000.
6,000	. 06435	24. 05	35. 00	. 06373	24. 07	40. 00	. 06275	24. 20	50. 00	6,000.
7,000	. 06229	23. 12	31. 67	. 06185	23. 20	36. 66	. 06083	23. 30	46. 66	7,000.
8,000	. 06040	22. 27	28. 33	. 05995	22. 33	33. 33	. 05889	22. 40	43. 33	8,000.
9,000	. 05855	21. 43	25. 00	. 05810	21. 49	30. 00	. 05712	21. 58	40. 00	9,000.
10,000	. 05668	20. 60	21. 67	. 05633	20. 69	26. 66	. 05531	20. 75	36. 66	10,000.
11,000	. 05487	19. 80	18. 33	. 05459	19. 91	23. 33	. 05368	20. 00	33. 33	11,000.
12,000	. 05325	19. 09	15. 00	. 05295	19. 16	20. 00	. 05209	19. 27	30. 00	12,000.
13,000	. 05158	18. 35	11. 67	. 05120	18. 40	16. 66	. 05049	18. 55	26. 66	13,000.
14,000	. 04992	17. 63	8. 33	. 04941	17. 64	13. 33	. 04888	17. 83	23. 33	14,000.
15,000	. 04834	16. 93	5. 00	. 04808	17. 03	10. 00	. 04743	17. 18	20. 00	15,000.
16,000	. 04674	16. 26	1. 67	. 04652	16. 37	6. 66	. 04596	16. 53	16. 66	16,000.
17,000	. 04522	15. 62	−1. 66	. 04502	15. 73	3. 33	. 04453	15. 90	13. 33	17,000.
18,000	. 04375	15. 00	−5. 00	. 04365	15. 13	0. 00	. 04313	15. 29	10. 00	18,000.
19,000	. 04231	14. 40	−8. 33	. 04213	14. 50	−3. 33	. 04177	14. 70	6. 66	19,000.
20,000	. 04090	13. 82	−11. 66	. 04075	13. 92	−6. 66	. 04041	14. 12	3. 33	20,000.

TABLE IIC.—*Surface barometric pressure, 30 inches*—Continued

h	540°			550°			560°			h
Feet	D_a	P	$t°$	D_a	P	$t°$	D_a	P	$t°$	Feet
Ground	0. 07315	30. 00	80. 00	0. 07160	30. 00	90. 00	0. 07005	30. 00	100. 00	Ground.
1,000	. 07141	28. 97	76. 66	. 06969	29. 00	86. 66	. 06842	29. 10	96. 66	1,000.
2,000	. 06921	28. 00	73. 33	. 06783	28. 03	83. 33	. 06654	28. 10	93. 33	2,000.
3,000	. 06726	27. 03	70. 00	. 06602	27. 10	80. 00	. 06485	27. 20	90. 00	3,000.
4,000	. 06543	26. 12	66. 66	. 06421	26. 18	76. 66	. 06306	26. 27	86. 66	4,000.
5,000	. 06357	25. 20	63. 33	. 06244	25. 28	73. 33	. 06133	25. 37	83. 33	5,000.
6,000	. 06171	24. 30	60. 00	. 06072	24. 42	70. 00	. 05963	24. 50	80. 00	6,000.
7,000	. 05977	23. 43	56. 66	. 05896	23. 55	66. 66	. 05801	23. 67	76. 66	7,000.
8,000	. 05818	22. 60	53. 33	. 05728	22. 72	63. 33	. 05637	22. 84	73. 33	8,000.
9,000	. 05646	21. 78	50. 00	. 05564	21. 92	60. 00	. 05480	22. 05	70. 00	9,000.
10,00	. 05473	20. 97	46. 66	. 05413	21. 18	56. 66	. 05329	21. 30	66. 66	10,000.
11,00	. 05309	20. 20	43. 33	. 05255	20. 42	53. 33	. 05175	20. 54	63. 33	11,000.
12,000	. 05160	19. 50	40. 00	. 05099	19. 68	50. 00	. 05028	19. 82	60. 00	12,000.
13,000	. 05010	18. 80	36. 66	. 04950	18. 97	46. 66	. 04878	19. 10	56. 66	13,000.
14,000	. 04857	18. 10	33. 33	. 04803	18. 28	43. 33	. 04748	18. 46	53. 33	14,000.
15,000	. 04704	17. 41	30. 00	. 04657	17. 63	40. 00	. 04610	17. 80	50. 00	15,000.
16,000	. 04559	16. 75	26. 66	. 04529	17. 00	36. 66	. 04470	17. 14	46. 66	16,000.
17,000	. 04416	16. 12	23. 33	. 04392	16. 37	33. 33	. 04344	16. 54	43. 33	17,000.
18,000	. 04279	15. 50	20. 00	. 04255	15. 75	30. 00	. 04218	15. 95	40. 00	18,000.
19,000	. 04148	14. 92	16. 66	. 04205	15. 15	26. 66	. 04091	15. 36	36. 66	19,000.
20,000	. 04020	14. 36	13. 33	. 03994	14. 58	23. 33	. 03970	14. 80	33. 33	20,000.

TABLE IID.—*Surface barometic pressure, 30.5 inches*

h	460°			470°			480°			h
Feet	D_a	P	t°	D_a	P	t°	D_a	P	t°	Feet
Ground	0. 08799	30. 50	0. 00	0. 08588	30. 50	10. 00	0. 08426	30. 50	20. 00	Ground.
1,000	. 08508	29. 28	−3. 33	. 08324	29. 30	6. 66	. 08160	29. 33	16. 66	1,000.
2,000	. 08225	28. 10	−6. 66	. 08060	28. 15	3. 33	. 07898	28. 20	13. 33	2,000.
3,000	. 07974	26. 98	−10. 00	. 07803	27. 05	0. 00	. 07653	27. 12	10. 00	3,000.
4,000	. 07695	25. 90	−13. 33	. 07549	25. 98	−3. 33	. 07407	26. 06	6. 66	4,000.
5,000	. 07423	24. 80	−16. 66	. 07289	24. 90	−6. 66	. 07154	24. 99	3. 33	5,000.
6,000	. 07163	23. 75	−20. 00	. 07039	23. 87	−10. 00	. 06921	23. 99	0. 00	6,000.
7,000	. 06917	22. 76	−23. 33	. 06800	22. 89	−13. 33	. 06689	23. 02	−3. 33	7,000.
8,000	. 06676	21. 80	−26. 66	. 06570	21. 95	−16. 66	. 06469	22. 10	−6. 66	8,000.
9,000	. 06450	20. 90	−30. 00	. 06352	21. 06	−20. 00	. 06258	21. 22	−10. 00	9,000.
10,000	. 06223	20. 01	−33. 33	. 06133	20. 18	−23. 33	. 06021	20. 36	−13. 33	10,000.
11,000	. 06003	19. 15	−36. 66	. 05922	19. 34	−26. 66	. 05846	19. 53	−16. 66	11,000.
12,000	. 05788	18. 32	−40. 00	. 05715	18. 52	−30. 00	. 05646	18. 72	−20. 00	12,000.
13,000	. 05573	17. 50	−43. 33	. 05511	17. 72	−33. 33	. 05452	17. 94	−23. 33	13,000.
14,000	. 05371	16. 73	−46. 66	. 05313	16. 95	−36. 66	. 05261	17. 18	−26. 66	14,000.
15,000	. 05179	16. 00	−50. 00	. 05125	16. 22	−40. 00	. 05077	16. 45	−30. 00	15,000.
16,000	. 04993	15. 30	−53. 33	. 04946	15. 53	−43. 33	. 04902	15. 76	−33. 33	16,000.
17,000	. 04813	14. 63	−56. 66	. 04770	14. 86	−46. 66	. 04733	15. 10	−36. 66	17,000.
18,000	. 04631	13. 96	−60. 00	. 04599	14. 21	−50. 00	. 04462	14. 45	−40. 00	18,000.
19,000	. 04456	13. 32	−63. 33	. 04428	13. 57	−53. 33	. 04401	13. 82	−43. 33	19,000.
20,000	. 04285	12. 70	−66. 66	. 04264	12. 96	−56. 66	. 04204	13. 22	−46. 66	20,000.

TABLE IID.—*Surface barometric pressure, 30.5 inches*—Continued

h	490°			500°			510°			h
Feet	D_a	P	$t°$	D_a	P	$t°$	D_a	P	$t°$	Feet
Ground	0. 08250	30. 50	30. 00	0. 08080	30. 50	40. 00	0. 07920	30. 50	50. 00	Ground.
1,000	. 07994	29. 35	26. 66	. 07836	29. 38	36. 66	. 07681	29. 40	46. 66	1,000.
2,000	. 07746	28. 24	23. 33	. 07585	28. 24	33. 33	. 07455	28. 34	43. 33	2,000.
3,000	. 07508	27. 18	20. 00	. 07370	27. 25	30. 00	. 07236	27. 32	40. 00	3,000.
4,000	. 07272	26. 14	16. 66	. 07140	26. 22	26. 66	. 07013	26. 30	36. 66	4,000.
5,000	. 07029	25. 09	13. 33	. 06906	25. 18	23. 33	. 06794	25. 30	33. 33	5,000.
6,000	. 06803	24. 11	10. 00	. 06692	24. 23	20. 00	. 06584	24. 35	30. 00	6,000.
7,000	. 06582	23. 16	6. 66	. 06478	23. 29	16. 66	. 06377	23. 42	26. 66	7,000.
8,000	. 06370	22. 25	3. 33	. 06275	22. 40	13. 33	. 06183	22. 55	23. 33	8,000.
9,000	. 06168	21. 38	0. 00	. 06079	21. 54	10. 00	. 06000	21. 70	20. 00	9,000.
10,000	. 05966	20. 53	−3. 33	. 05886	20. 71	6. 66	. 05802	20. 88	16. 66	10,000.
11,000	. 05769	19. 71	−6. 66	. 05696	19. 90	3. 33	. 05807	20. 10	13. 33	11,000.
12,000	. 05579	18. 92	−10. 00	. 05516	19. 12	0. 00	. 05630	19. 34	10. 00	12,000.
13,000	. 05392	18. 15	−13. 33	. 05323	18. 32	−3. 33	. 05286	18. 60	6. 66	13,000.
14,000	. 05208	17. 40	−16. 66	. 05161	17. 63	−6. 66	. 05109	17. 85	3. 33	14,000.
15,000	. 05028	16. 67	−20. 00	. 04984	16. 90	−10. 00	. 04939	17. 12	0. 00	15,000.
16,000	. 04859	15. 99	−23. 33	. 04830	16. 22	−13. 33	. 04780	16. 45	−3. 33	16,000.
17,000	. 04694	15. 33	−26. 66	. 04660	15. 57	−16. 66	. 04625	15. 80	−6. 66	17,000.
18,000	. 04536	14. 70	−30. 00	. 04506	14. 94	−20. 00	. 04479	15. 19	−10. 00	18,000.
19,000	. 04379	14. 08	−33. 33	. 04355	14. 33	−23. 33	. 04332	14. 58	−13. 33	19,000.
20,000	. 04222	13. 47	−36. 66	. 04109	13. 73	−26. 66	. 04187	13. 99	−16. 66	20,000.

h	515°			520°			530°			h
Feet	D_a	P	t°	D_a	P	t°	D_a	P	t°	Feet
Ground	0. 07833	30. 50	55. 00	0. 07753	30. 50	60. 00	0. 07519	30. 50	70. 00	Ground.
1,000	. 07633	29. 42	51. 67	. 07529	29. 42	56. 66	. 07380	29. 44	66. 66	1,000.
2,000	. 07352	28. 37	48. 33	. 07315	28. 39	53. 33	. 07219	28. 43	63. 33	2,000.
3,000	. 07168	27. 35	45. 00	. 07103	27. 38	50. 00	. 06972	27. 44	60. 00	3,000.
4,000	. 06951	26. 34	41. 67	. 06890	26. 38	46. 66	. 06769	26. 46	56. 66	4,000.
5,000	. 06734	25. 34	38. 33	. 06675	25. 38	43. 33	. 06563	25. 48	53. 33	5,000.
6,000	. 06531	24. 41	35. 00	. 06477	24. 46	40. 00	. 06372	24. 57	50. 00	6,000.
7,000	. 06329	23. 49	31. 67	. 06279	23. 55	36. 66	. 06183	23. 68	46. 66	7,000.
8,000	. 06136	22. 62	28. 33	. 06092	22. 69	33. 33	. 05999	22. 82	43. 33	8,000.
9,000	. 05959	21. 78	25. 00	. 05907	21. 85	30. 00	. 05824	22. 00	40. 00	9,000.
10,000	. 05768	20. 96	21. 67	. 05728	21. 04	26. 66	. 05651	21. 20	36. 66	10,000.
11,000	. 05593	20. 18	18. 33	. 05555	20. 26	23. 33	. 05484	20. 43	33. 33	11,000.
12,000	. 05419	19. 42	15. 00	. 05385	19. 50	20. 00	. 05320	19. 68	30. 00	12,000.
13,000	. 05254	18. 69	11. 67	. 05220	18. 77	16. 66	. 05158	18. 95	26. 66	13,000.
14,000	. 05082	17. 95	8. 33	. 05053	18. 04	13. 33	. 04999	18. 23	23. 33	14,000.
15,000	. 04911	17. 22	5. 00	. 04886	17. 32	10. 00	. 04837	17. 52	20. 00	15,000.
16,000	. 04754	16. 55	1. 67	. 04731	16. 65	6. 66	. 04685	16. 85	16. 66	16,000.
17,000	. 04603	15. 90	−1. 66	. 04579	16. 00	3. 33	. 04540	16. 21	13. 33	17,000.
18,000	. 04456	15. 28	−5. 00	. 04440	15. 39	0. 00	. 04401	15. 60	10. 00	18,000.
19,000	. 04313	14. 68	−8. 33	. 04298	14. 79	−3. 33	. 04262	15. 00	6. 66	19,000.
20,000	. 04170	14. 09	−11. 67	. 04157	14. 20	−6. 66	. 04124	14. 41	3. 33	20,000.

TABLE IID.—*Surface barometric pressure, 30.5 inches*—Continued

h	540°			550°			560°			*h*
Feet	D_a	*P*	*t*°	D_a	*P*	*t*°	D_a	*P*	*t*°	Feet
Ground	0. 07433	30. 50	80. 00	0. 07281	30. 50	90. 00	0. 07124	30. 50	100. 00	Ground.
1,000	. 07235	29. 47	76. 66	. 07088	29. 49	86. 66	. 06940	29. 51	96. 66	1,000.
2,000	. 07038	28. 47	73. 33	. 06903	28. 52	83. 33	. 06767	28. 57	93. 33	2,000.
3,000	. 06844	27. 50	70. 00	. 06715	27. 56	80. 00	. 06587	27. 62	90. 00	3,000.
4,000	. 06649	26. 54	66. 66	. 06530	26. 62	76. 66	. 06410	26. 70	86. 66	4,000.
5,000	. 06456	25. 59	63. 33	. 06346	25. 69	73. 33	. 06236	25. 79	83. 33	5,000.
6,000	. 06268	24. 68	60. 00	. 06165	24. 79	70. 00	. 06062	24. 90	80. 00	6,000.
7,000	. 06093	23. 81	56. 66	. 05993	23. 94	66. 66	. 05900	24. 07	76. 66	7,000.
8,000	. 05920	22. 96	53. 33	. 05821	23. 09	63. 33	. 05736	23. 23	73. 33	8,000.
9,000	. 05742	22. 15	50. 00	. 05661	22. 30	60. 00	. 05579	22. 45	70. 00	9,000.
10,000	. 05579	21. 37	46. 66	. 05503	21. 53	56. 66	. 05427	21. 69	66. 66	10,000.
11,000	. 05425	20. 61	43. 33	. 05348	20. 78	53. 33	. 05246	20. 95	63. 33	11,000.
12,000	. 05256	19. 86	40. 00	. 05193	20. 04	50. 00	. 05130	20. 22	60. 00	12,000.
13,000	. 05101	19. 14	36. 66	. 05041	19. 32	46. 66	. 04981	19. 50	56. 66	13,000.
14,000	. 04944	18. 42	33. 33	. 04890	18. 61	43. 33	. 04836	18. 80	53. 33	14,000.
15,000	. 04788	17. 72	30. 00	. 04741	17. 92	40. 00	. 04755	18. 12	50. 00	15,000.
16,000	. 04641	17. 05	26. 66	. 04596	17. 25	36. 66	. 04551	17. 45	46. 66	16,000.
17,000	. 04497	16. 41	23. 33	. 04459	16. 62	33. 33	. 04418	16. 82	43. 33	17,000.
18,000	. 04363	15. 80	20. 00	. 04322	16. 00	30. 00	. 04287	16. 21	40. 00	18,000.
19,000	. 04226	15. 20	16. 66	. 04194	15. 41	26. 66	. 04160	15. 62	36. 66	19,000.
20,000	. 04095	14. 63	13. 33	. 04065	14. 84	23. 33	. 04037	15. 05	33. 33	20,000.

TABLE III.—*For use in solving adiabatic formulas*

$N^{1.4}$

N	0	1	2	3	4	5	6	7	8	9	N
1.0	1.000	1.014	1.028	1.042	1.057	1.071	1.085	1.099	1.114	1.128	1.0
1.1	1.143	1.157	1.172	1.187	1.201	1.216	1.231	1.246	1.261	1.276	1.1
1.2	1.291	1.306	1.321	1.336	1.351	1.367	1.382	1.397	1.413	1.428	1,2
1.3	1.444	1.459	1.475	1.491	1.506	1.522	1.538	1.554	1.570	1.586	1.3
1.4	1.602	1.618	1.634	1.650	1.666	1.682	1.698	1.715	1.731	1.748	1.4
1.5	1.764	1.781	1.797	1.814	1.830	1.847	1.864	1.880	1.897	1.914	1.5
1.6	1.931	1.948	1.965	1.982	1.999	2.016	2.033	2.050	2.067	2.085	1.6
1.7	2.102	2.119	2.137	2.154	2.171	2.189	2.207	2.224	2.242	2.259	1.7
1.8	2.277	2.295	2.313	2.330	2.348	2.366	2.384	2.402	2.420	2.438	1.8
1.9	2.456	2.474	2.492	2.511	2.529	2.547	2.565	2.584	2.602	2.621	1.9
2.0	2.639	2.657	2.676	2.695	2.713	2.732	2.751	2.769	2.788	2.807	2.0

$N^{\frac{1}{1.4}}=N^{0.71}$

N	0	1	2	3	4	5	6	7	8	9	N
1.0	1.000	1.007	1.014	1.021	1.028	1.035	1.042	1.050	1.057	1.063	1.0
1.1	1.070	1.077	1.084	1.091	1.098	1.105	1.112	1.119	1.126	1.132	1.1
1.2	1.139	1.146	1.153	1.159	1.166	1.173	1.179	1.186	1.193	1.200	1.2
1.3	1.206	1.213	1.219	1.226	1.233	1.239	1.246	1.252	1.259	1.265	1.3
1.4	1.272	1.278	1.285	1.291	1.298	1.304	1.310	1.317	1.323	1.330	1.4
1.5	1.336	1.342	1.349	1.355	1.361	1.368	1.374	1.380	1.386	1.393	1.5
1.6	1.399	1.405	1.411	1.418	1.424	1.430	1.436	1.442	1.449	1.455	1.6
1.7	1.461	1.467	1.473	1.479	1.485	1.491	1.497	1.504	1.510	1.517	1.7
1.8	1.522	1.528	1.534	1.540	1.546	1.552	1.558	1.564	1.570	1.576	1.8
1.9	1.582	1.588	1.594	1.599	1.605	1.611	1.617	1.623	1.629	1.635	1.9
2.0	1.641	1.647	1.652	1.658	1.664	1.670	1.675	1.681	1.687	1.693	2.0

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[A. G. 062.12 (1-25-40).]

BY ORDER OF THE SECRETARY OF WAR:

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