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ABSTRACT

As the fourteenth lesson of the Articulated Multimedia Physics Course, instructional materials are presented in this study guide with relation to gases, gas laws, and absolute temperature. The topics are concerned with the kinetic theory of gases, thermometric scales, Charles' law, ideal gases, Boyle's law, absolute zero, and gas pressures. The content is arranged in scrambled form, and the use of matrix transparencies is required for students to control their learning activities. Students are asked to use a magnetic tape playback, instructional tapes, and single concept films at the appropriate place in conjunction with the worksheet. Included are a homework problem set and illustrations for explanation purposes. Related documents are SE 015 963 through SE 015 976. (CC)

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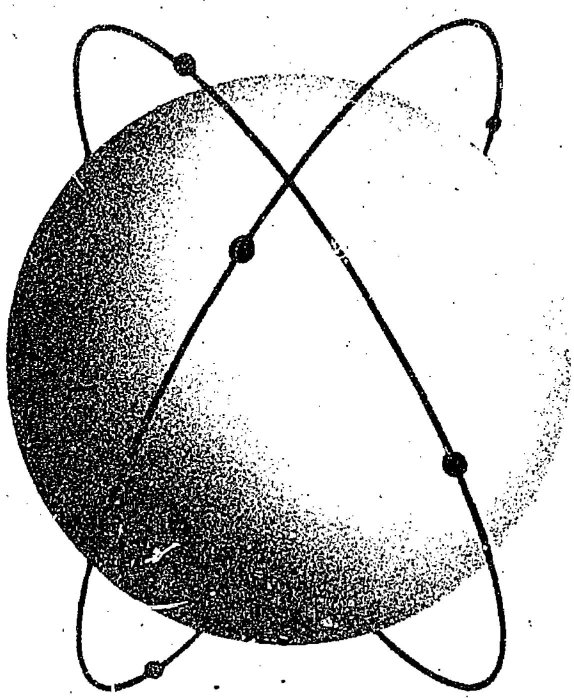
ARTICULATED MULTIMEDIA PHYSICS



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LESSON 14

NEW YORK INSTITUTE OF TECHNOLOGY
OLD WESTBURY, NEW YORK

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ARTICULATED MULTIMEDIA PHYSICS

Lesson Number 14

GASES, THE GAS LAWS, AND ABSOLUTE TEMPERATURE

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IMPORTANT: Your attention is again called to the fact that this is not an ordinary book. It's pages are scrambled in such a way that it cannot be read or studied by turning the pages in the ordinary sequence. To serve properly as the guiding element in the Articulated Multimedia Physics Course, this Study Guide must be used in conjunction with a Program Control equipped with the appropriate matrix transparency for this Lesson. In addition, every Lesson requires the availability of a magnetic tape playback and the appropriate cartridge of instructional tape to be used, as signaled by the Study Guide, in conjunction with the Worksheets that appear in the blue appendix section at the end of the book. Many of the lesson Study Guides also call for viewing a single concept film at an indicated place in the work. These films are individually viewed by the student using a special projector and screen; arrangements are made and instructions are given for synchronizing the tape playback and the film in each case.

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Now that you have some familiarity with the molecular activities constituting internal energy, we are ready to study gases. We will cover some physical events and concepts that deal with gases.

We picture a gas as consisting of molecules moving about in a container with random motion, colliding with each other and with the walls of the container. To describe a given specimen of gas, we consider its volume mass, density, pressure, temperature, and constituents. We try to establish relationships between these factors. When the relationships are experimentally verified, we attempt to develop a general theory to explain them!

In common with other phases of mechanics, it is much simpler to deal with an ideal situation first. Corrections for actual conditions will come later. So we begin by defining an ideal gas. Remember, an ideal gas does not exist. However, many real gases closely approach the specifications for an ideal gas. Looking over the assumptions in the definition of an ideal gas, you will recognize that none are "wild." They are all reasonable and close to actual conditions.

Please turn to page 122 in the blue appendix.

These are the assumptions which form the definition of an ideal gas:

(1) The molecules move at random within the container.
(2) Every molecule has the same mass as every other molecule of the same gas.
(3) The molecules are negligibly small compared to the distances they travel between collisions.
(4) Collisions between molecules and between the molecules and the walls of the container are perfectly elastic; that is, mechanical energy is conserved.
(5) The molecules do not exert forces on each other except during collisions.

These assumptions enable us to construct a model of an ideal gas. As we develop physical laws relating to ideal gases, we must never forget that applications of these laws are limited to ideal-gas conditions.

Explanations of the behavior of a gas in this model form part of the Kinetic Theory of Gases. Although still a theory, the concepts and ramifications of the kinetic theory have led to very fruitful results.

This lesson begins with a consideration of the pressure of a gas: what causes it, how it depends on other things, how it may be increased or decreased, and other factors. These ideas will lead to the laws about gases and an understanding of the meaning and usefulness of the concept of absolute zero.

Please go on to page 3.

ERIC

In our model of a gas, we picture widely spaced molecules moving randomly in empty space with speeds a little faster than sound (of the order of 400 m/sec), colliding with each other and with the walls of the container.

The molecules fly against and rebound from the walls like handballs. As each collides with the wall, it momentarily pushes against it. Figure 1 shows a few molecules in a container.

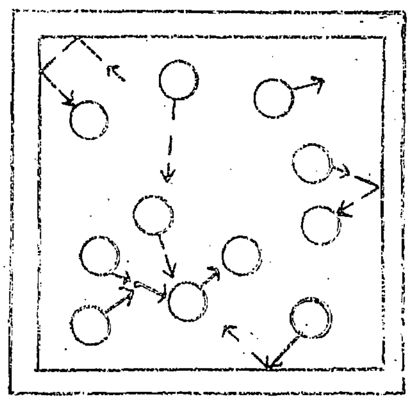

Figure 1

If this gas were 2.0 g of hydrogen, about 6×10^{23} molecules would be present. With so many molecules flying about, it is safe to guess that for every molecule ramming into the right-hand wall at a given instant, there is one colliding with the left-hand wall; the same would be true for the upper and lower walls. Similarly, because of the tremendous number of molecules in the container, it is equally safe to hypothesize that every square centimeter of the four walls is being hit by the same number of molecules, on the average, as every other square centimeter in a given interval of time.

Suppose the container in Figure 1 is made of very light material possessing almost no inertia. If the number of molecules colliding with each unit area on each of the four walls is not equal for a given period, then what would you expect?

(1)

A The container is stationary.

B The container is moving about.

YOUR ANSWER --- A

You are correct.

NOTEBOOK ENTRY
Lesson 14

(Item 4)

(d) Boyle's Law and Charles' law may be combined into a single expression to give us a general gas law:

$$\frac{PV}{T} = \frac{P'V'}{T'}$$

(e) Sample problem: (Copy the problem next presented as an illustration of the use of the combined law.)

Sample Problem: Chemists are often called upon to reduce a gas to conditions of standard temperature and pressure. Standard temperature is 0° C and standard pressure is 76.0 cm of mercury. Suppose you have a gas with an initial volume of 500 cm^3, at a temperature of 20° C, and a pressure of 75.0 cm of mercury. What volume will the gas have when reduced to STP? (STP is the abbreviation for standard temperature and pressure.)

It is important to list the initial and new values of the known quantities, this way:

Initial	New
$P = 75.0$ cm	$P' = 76.0$ cm
$V = 500\ cm^3$	$V' = ???$
$T = 293^\circ$ K	$T' = 273^\circ$ K

Next, write the equation and solve for the unknown:

$$\frac{PV}{T} = \frac{P'V'}{T'}$$

so that

$$V' = \frac{PVT'}{P'T}$$

or better

$$V' = V \times \frac{P}{P'} \times \frac{T'}{T}$$

Substitute and solve for V', write your answer, then check it by turning to page 26.

YOUR ANSWER --- A

Apparently, your approach to the solution was correct but you have an error in order of magnitude. It is important that you pay careful attention to all the details of the answer choices given.

Please return to page 26 and select the right answer.

ERIC

YOUR ANSWER --- A

No, there is no error here:

$$
\begin{aligned}
{}^{\circ}K &= {}^{\circ}C + 273 \\
&= 212^{\circ}\ C + 273^{\circ} \\
&= 485^{\circ}\ K
\end{aligned}
$$

Please return to page 10. Try another answer.

YOUR ANSWER --- C

No, one of the given answe is right.

Perhaps you are not handling the proportion correctly. Let's see.

The product of the given pressure (2.0 at or 20 nt/cm^2) and the given volume (600 cm^3) is equal to a constant. We know, therefore, that the product of the new pressure (3.0 atm or 30 nt/cm^2) and the new volume (unknown) must be equal to the same number, since it is a constant. But, things equal to the same thing are equal to each other, so the two products may be equated.

Make a habit of using the following symbols.

V = original volume   P = original pressure
V' = new volume   P' = new pressure

So, since PV = k and also P'V' = k, then PV = P'V'. This is the most convenient form of Boyle's Law for our purposes.

In this problem we have:

V = 600 cm^3	P = 2.0 atm	(or 20 nt/cm^2)
V' = ???	P' = 3.0 atm	(or 30 nt/cm^2)

And since PV = P'V', then:

$$2.0 \text{ atm} \times 600 \text{ cm}^3 = 3.0 \text{ atm} \times V'$$

Now, all you have to do is solve for V', the new volume.

Please return to page 62 and select another answer.

YOUR ANSWER --- C

Physicists believe that all molecular motion does not cease at 0^{o} K. Thus, some kinetic energy must be present at the molecular level. However, this does not lead to the conclusion that only internal kinetic energy is present; nothing is said to enable us to conclude that there is no potential energy in a body at absolute zero.

Please return to page 104 and choose a better answer.

ERIC

YOUR ANSWER --- A

Your choice of this group tells us that you didn't work all of these out carefully. Three of the four answers are way off.

Please return to page 53, go back to the problem, and solve all four parts please. Then select another answer.

ERIC

YOUR ANSWER --- A

You are correct. The Kelvin scale always r 's 273^{o} higher than the Centigrade scale; thus, you add 273 to the Centig: reading to obtain the Kelvin equivalent. (Actually, this is a very sligh approximation because 0^{o} K = -273.16^{o} C, but we shall use the rounded 273 in our study.)

A few practice exercises in conversion from ^{o}K to ^{o}C and vice-versa would be helpful here.

In the following group of conversions, one error has been introduced intentionally. Check each one for yourself; then choose the one that has an error.

(20)

A	212^{o} C	485^{o} K
B	14^{o} C	287^{o} K
C	-1^{o} C	274^{o} K
D	-20^{o} C	253^{o} K

YOUR ANSWER --- A

The answer is not reasonable.

If we agree that 0° K is the lowest temperature to which matter can be cooled, then the outside body cannot have a lower temperature than body A. However, heat flows only from a body of higher temperature to one of lower temperature. Hence, it necessarily follows that heat will not flow out of A into any other body regardless of the latter's temperature.

Please return to page 84. You know the right answer now.

YOUR ANSWER --- B

When two variables are inversely proportional, the difference between various pairs of values will not reveal it.

Surely your notes do not say this! Please check back after returning to page 79 but before you choose another answer.

ERIC

YOUR ANSWER --- A

When you write it this way, you can appreciate the error at once. To determine what fractional part of 1,000 is represented by the number 3.66, the fraction should be set up this way:

$$\frac{3.66}{1{,}000}$$

This should now be reduced so that "1" appears in the numerator. Do it. Then please return to page 61 and make your new selection.

YOUR ANSWER --- C

This is the best answer, although it is not significant, unless we clarify "very little" internal energy.

Suppose a body at 0^{o} K has the smallest possible amount of internal energy, then there is no temperature at which a body can have less internal energy than at 0^{o} K. This doesn't go far enough.

To arrive at our final definition of absolute zero, let's use the idea just expressed. However, we shall push it a bit further.

Suppose a body A was at 0.00000^{o} K and body B, which is in contact with it, is at 0.00001^{o} K. Will there be a transfer of energy from one to the other? If so, in what direction will it occur?

(28)

A Heat will flow from body B to body A until both are at 0.00000^{o} K.

B Heat will flow from body B to body A until the temperatures are equalized.

C There will be no transfer of energy since both bodies are very cold.

YOUR ANSWER --- B

You are incorrect. Since we are dealing with 1,000 cm^3 of the gas, and since the temperature will be reduced 250 C^o, then the contraction can be computed from:

$$1{,}000\ cm^3 \times \frac{250}{273}$$

When you obtain the answer to this calculation, it is to be subtracted from the original volume to find the new volume. This does not turn out to be 91.6 cm^3.

Repeat the calculation, find your error, and then return to page 67 to select the right answer.

ERIC

YOUR ANSWER --- B

Almost, but not quite.

Three of the four answers in this group are correct, but there is one error.

Check your work to find the error. Then please return to page 53 and make another selection.

ERIC

YOUR ANSWER --- B

You are incorrect.

Either you're trying to work too fast, or you have missed the point. In either case, you will find it helpful to verbalize the expression $PV/T = k$. Thus, this relationship is: given a certain volume of gas V at a pressure P and an absolute temperature T, first multiply the pressure and volume (PV) and then divide this product by the absolute temperature (PV/T). This results in a certain number, k. Next, allow the pressure P and the temperature T to vary; say they go to the new values P' and T'. Now measure the new volume V', and again perform the same arithmetic operation, P'V'/T'. The new number will be the same number as before, k.

If you check the above answer, you will find an inversion that doesn't belong there.

Please return to page 101 and pick the right answer.

ERIC

YOUR ANSWER --- B

This answer is incorrect.

Have you forgotten how to handle problems involving a proportionality?

The product of the given pressure (2.0 atm or 20 nt/cm^2) and the given volume (600 cm^3) is equal to a constant. We know, therefore, that the product of the <u>new</u> pressure (3.0 atm or 30 nt/cm^2) and the <u>new</u> volume (unknown) must be equal to the same number, since it is a constant. But, things equal to the same thing are equal to each other, so the two products may be equated.

Make a habit of using the following symbols:

V = original volume	P = original pressure
V' = new volume	P' = new pressure

So, since PV = k and also P'V' = k, then <u>PV = P'V'</u>. This is the most useful form of Boyle's Law for our purposes.

In this problem, we have:

V = 600 cm^3	P = 2.0 atm	(or 20 nt/cm^2)
V' = ???	P' = 3.0 atm	(or 30 nt/cm^2)

Thus, since PV = P'V', then:

$$2.0 \text{ atm} \times 600 \text{ cm}^3 = 3.0 \text{ atm} \times V'$$

Now, solve for V'.

Please return to page 62, solve the problem, and choose your answer.

You have now completed the study portion of Lesson 14 and your Study Guide Computer Card and A V Computer Card should be properly punched in accordance with your performance in this Lesson.

You should now proceed to complete your homework reading and problem assignment. The problem solutions must be clearly written out on $8\frac{1}{2}$" x 11" ruled, white paper, and then submitted with your name, date, and identification number. Your instructor will grade your problem work in terms of an objective preselected scale on a Problem Evaluation Computer Card and add this result to your computer profile.

You are eligible for the Post Test for this Lesson only after your homework problem solutions have been submitted. You may then request the Post Test which is to be answered on a Post Test Computer Card.

Upon completion of the Post Test, you may prepare for the next Lesson by requesting the appropriate

1. study guide
2. program control matrix
3. set of computer cards for the lesson
4. audio tape

If films or other visual aids are needed for this lesson, you will be so informed when you reach the point where they are required. Requisition these aids as you reach them.

Good Luck!

ERIC

YOUR ANSWER --- D

This is incorrect.

You realized that the force exerted by the 10-nt weight is acting on an area of 10 cm^2. Then you found the pressure, using $P = F/A$ or $P = 10\ nt/10\ cm^2 = 1\ nt/cm^2$. So far this is correct.

However, you forgot that the atmosphere is also pressing down on the top of the piston with a pressure of 10 nt/cm^2. This must be included in your calculation.

Please return to page 105 and correct your error by choosing the right answer.

ERIC

YOUR ANSWER --- C

You are correct. To find the fractional part, you merely divide 3.66 by 1,000 this way:

$$\frac{3.66}{1,000}$$

To reduce this to a fraction in which "1" appears in the numerator, divide top and bottom by 3.66. This yields 1/273.

Continuing with contracting gas, we note that experiments show that any gas of volume 1,000 cm^3 starting at 0^o C contracts 3.66 cm^3 for each C^o drop in temperature, provided that the pressure remains the same. Further, this can be expressed by: <u>Any gas contracts 1/273 of its volume at 0^o C for each C^o drop in temperature.</u> This is a much more general way to describe the volumetric change of a gas that results from temperature variation.

For example, 1 cm^3 of hydrogen at 0^o C contracts 1/273 of a cubic centimeter for each degree of temperature reduction; that is, it loses 0.00366 cm^3 for each degree. Ten cm^3 of oxygen contract 1/273 of 10 cm^3, or 0.0366 cm^3 for each degree; 100 cm^3 of nitrogen contract 1/273 of 100 cm^3, or 0.366 cm^3 for each degree; and so forth.

Now, answer this next question: what will be the new volume of 273 cm^3 of a gas which is cooled from 0^o C to -5.00^o C? Choose the right answer from those listed below.

(17)

A 254.7 cm^3

B 271.17 cm^3

C Neither of these is correct.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

YOUR ANSWER --- D

You are absolutely correct! If a is inversely proportional to b, then we may write: $a = k/b$. By multiplying both sides by b, this becomes $ab = k$, which shows that when two quantities are inversely proportional, <u>the product of any associated pair of values will be a constant</u>.

Figure 7 shows these pairs of values.

total P (nt/cm^2)	volume V (cm^3)
20.5	10.0
30.5	6.8
40.5	5.1
50.5	4.1
60.5	3.5

Figure 7

To test for an inverse proportion, multiply the two quantities that make up each pair. Record the products with the full number of digits, without rounding. Note that the volume column contains numbers with only two significant figures; hence the product PV will ultimately have only two significant figures for each pair. With this in mind, does the data enable you to conclude that there is a strong possibility that the volume occupied by a gas is inversely proportional to the total pressure exerted on it?

(10)

A Yes.

B No.

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YOUR ANSWER --- A

This conclusion is incorrect. You were misled by the fact that the downward force acting on Piston 1 is 5 times as great as the downward force on Piston 2.

If you wish, refer to Figure 3 on page 66. You thought Piston 1 would move downward, compressing the gas still further, and that this compression would exert a force on Piston 2, pushing it upward.

You must remember that equal numbers of gas molecules strike equal areas in equal times, and that the area of Piston 1 is 5 times as great as that of Piston 2. This means the upward force due to molecular impact on Piston 1 must also be 5 times as great as the corresponding force on Piston 2.

Where does that leave you? True, the downward force of the 50-nt weight is 5 times as large as the downward force of the 10-nt weight; however, the upward force on Piston 1 is also 5 times that acting on Piston 2.

Please return to page 66. You should be able to choose the right answer now.

CORRECT SOLUTION: $V' = V \times \frac{P}{P'} \times \frac{T'}{T}$

$$V' = 500\ cm^3 \times \frac{75.0\ cm}{76.0\ cm} \times \frac{273^o\ K}{293^o\ K}$$

$$V' = \underline{460}\ \underline{cm^3}$$

Try this problem on your own:

A quantity of nitrogen occupies 2.00×10^3 liters at STP. What is its volume at 20.0^o C and 735 mm of pressure?

List the PVT and the P'V'T' values. Write the equation in which V' appears as a function of V, P, P', T, and T;. Substitute and solve for V'. Does your answer agree with any one of the answers listed below? If so, choose that answer; if not, press the button associated with the last item.

(25)

A 2.22×10^4 liters.

B 2.07×10^3 liters.

C 1.93×10^3 liters.

D None of these is correct.

YOUR ANSWER --- B

Try this equation, for instance, at the temperature of boiling water: at this temperature $^{o}C = 100$ and $^{o}K = 373$. Now substitute in this:

$$^{o}C = 373^{o}\ K + 273^{o}$$

To be correct, the answer should be 100^{o} C. But it isn't. Therefore, the equation you chose is incorrect.

Do you see the error? Correct it, return to page 32 and choose a new answer.

YOUR ANSWER --- B

What happened to the decimal point? You just don't drop a decimal point without a reason.

Furthermore, there is an inversion that introduces another error.

Let's take a simple example. What fractional part of 100 is the number 4? To do this, you set up a fraction like this:

$$\frac{4}{100}$$

Then, you reduce the fraction to its lowest terms and obtain $\frac{1}{25}$.

Why not do exactly the same thing with our problem?

Please return to page 61. Choose the right answer.

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This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

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YOUR ANSWER --- D

Pressure is force per unit area.

You learned that the word per always signifies a fraction-bar. Where is the fraction or the fraction bar here?

If 10 apples cost 50 cents, what is the cost per apple? The answer is 5 cents per apple, of course. How did you find it? You divided one figure by the other.

Please return to page 91 and select an alternative answer.

ERIC

YOUR ANSWER --- C

You're being careless in your thinking. You are forgetting the weight ofthe piston itself.

A total force of 10 nt due to the weight alone acts on the piston and therefore on the gas. The pressure, not the total force, is what you must find. Furthermore, the effect of atmospheric pressure in determining the pressure of the gas must be taken into consideration.

Please return to page 105. Take all factors into account. See if you can calculate the correct answer.

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YOUR ANSWER --- C

You are absolutely right.

$$\text{Contraction} = 1{,}000\ \text{cm}^3 \times \frac{250}{273} = 916\ \text{cm}^3$$

$$\text{New volume} = 1{,}000\ \text{cm}^3 - 916\ \text{cm}^3 = \underline{84.0\ \text{cm}^3}$$

Use of absolute zero, -273° C, as the zero-point of a new thermometric scale was first suggested by Lord Kelvin (William Thomson, 19th century British physicist). On this scale, known as either the absolute or Kelvin scale, the intervals between degrees is exactly the same as the Centigrade interval, but on this scale absolute zero is shown as "zero-point," as seen in Figure 11.

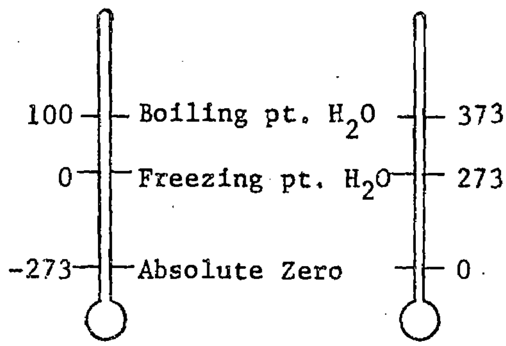


Figure 11

This drawing represents scales, not actual thermometers. Because of the difference in starting points, the Centigrade scale reads -273° for the same temperature as Kelvin zero, or 0° K. Similarly, the freezing point of water is 0° C and 273° K, respectively. Thus, the boiling point of water is both 100° C and 373° K. To convert from one scale to the other is a simple matter. Which one of the following equations is correct for conversion?

(19)

A $^{\circ}K = {}^{\circ}C + 273^{\circ}$

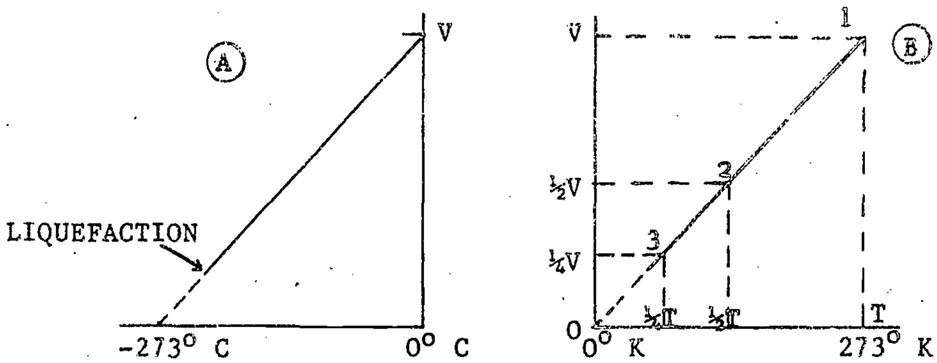
B $^{\circ}C = {}^{\circ}K + 273^{\circ}$

C $^{\circ}C + {}^{\circ}K = 273^{\circ}$

YOUR ANSWER --- C

You are quite right. It should be: $^{o}K = -1^{o}\ C + 273^{o} = \underline{272^{o}\ K}$.

The principles presented earlier can now help establish a second important gas law. (The first is Boyle's Law, as you will remember.) Refer to A and B in Figure 12.



CENTIGRADE

KELVIN
(ABSOLUTE)

Figure 12

The graph in A shows a cooling curve for helium plotted in terms of volume V against Centigrade temperature. The graph is a straight line, since the volume decreases linearly with temperature. The solid portion of the graph is longer than the one we drew for nitrogen, because helium must be cooled to a much lower temperature before it liquefies. The dotted portion is the extrapolation to absolute zero. This is familiar to you, because it is similar to the nitrogen cooling curve we analyzed earlier.

Now look at B. Which of the statement below is the true one?

(21)

A The curve in B is identical to that of A, but has merely been transferred to a Kelvin axis.

B A and B have different slopes.

C A is a minus curve while B is a plus curve.

YOUR ANSWER --- B

There is an error in your arithmetic.

You may have inverted the ratio of pressures or temperatures.

Please try to locate your error; then return to page 26 and select the right answer.

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This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

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YOUR ANSWER --- A

You do get an answer of 20.5 by dividing the volume by 0.488. But how does this apply to the question? You should be able to explain all your operations logically before you make use of them.

The values in the fifth column of Figure 6 on page 71 are very important. They are obtained from a logical step derived from the sense of the problem.

Please think about this before again returning to page 71 and choosing another answer.

YOUR ANSWER --- C

There is an error in your arithmetic. You may have inverted the ratio of temperatures or pressures.

Please try to locate your error; then return to page 26 and select the correct answer.

ERIC

YOUR ANSWER --- B

To find the absolute force acting on the gas (which is the only way we have to determine the pressure of the gas), we must know the magnitudes of all the forces acting on the piston. There are three contributing factors:

(1) The weight of the objects we lay on the piston table. We can choose any value for these.

(2) The pressure of the atmosphere. This is to be taken as 10 nt/cm^2.

(3) The weight of the piston-rod assembly, since this assembly also presses down on the gas and contributes to its final pressure.

Please return to page 111 and select the alternative answer.

ERIC

YOUR ANSWER --- C

You are correct. The fact that both axes start at zero, plus the fact that the graph is a straight line, are enough to establish a direct proportionality. Therefore, the volume of a gas is directly proportional to its Kelvin (absolute) temperature.

This leads to:

$$V = kT$$

where V = volume in <u>any</u> unit, and T = Kelvin temperature. This relationship is called Charles' Law and is certainly worth a Notebook Entry.

Please proceed to the Notebook Entry by turning to page 40.

ERIC

NOTEBOOK ENTRY
Lesson 14

4. Charles' Law

(a) For an ideal gas, or a gas under low pressure at or about room temperature, the volume of the gas is directly proportional to the Kelvin (absolute) temperature, if the pressure is constant.

$$V = kT \quad \text{(with P constant)}$$

(b) This direct relationship is more usefully expressed as

$$\frac{V}{T} = \frac{V'}{T'} \quad \text{(with P constant)}$$

(c) Sample problem: (Copy problem and solution below.)

Sample Problem: A tank contains exactly 500 cm^3 of helium at 20.0° C. If the temperature of the gas is increased to 40.0° C, what will be the new volume of the helium, provided that the pressure does not change?

You have the necessary equation, and three of the four quantities involved in Charles' Law are given. Solve the problem. Then choose an answer from those given below:

(23)

A New volume = 1,000 cm^3

B New volume = 468 cm^3

C New volume = 534 cm^3

D None of these answers is correct.

ERIC

YOUR ANSWER --- C

This is not correct. To show you why, let's use an analogy.

Ten applies cost 50 cents. To find the cost of one apple, or cost per apple, you do this:

$$\text{cost per apple} = \frac{50 \text{ cents}}{\text{apples}} = 5 \text{ cents per apple.}$$

Now, pressure is force per unit area. If you try to define it as A/F, you are expressing it backwards, because this reads area per unit of force, which is meaningless.

Please return to page 91 and choose a more meaningful answer.

YOUR ANSWER --- A

According to previous discussion, this statement cannot be true.

There is strong evidence to show that even at absolute zero there is still some molecular motion. In that case, there must be some internal energy present.

Please return to page 104. One of the answers is far better than the others.

YOUR ANSWER --- A

You are correct.

The products of the associated values of P and V are given in Figure 8 before rounding.

total P (nt/cm^2)	volume V (cm^3)	P x V
20.5	10.0	205.0
30.5	6.8	207.4
40.5	5.1	206.55
50.5	4.1	207.05
60.5	3.5	211.75

Figure 8

When reduced to two significant figures, the products all become 210. This clearly established the fact that the volume of a gas is inversely proportional to the total pressure acting on it or:

$$V = \frac{k}{P} \quad \text{conveniently written} \quad PV = k$$

This relationship was first established by Robert Boyle, an English scientist (1662), and is known as Boyle's Law. It is the first of our ideal gas laws, so-called because it is only approximately true for real gases. Boyle's Law gives results that are closest to ideal when the range of pressure variation is small, and when the highest pressure exerted on the gas is also kept small. A gas to low pressure behaves more like an ideal gas because its molecules are far apart and have little effect on each other. Before we make this a Notebook Entry, we must answer one more question: what else in addition to pressure governs the volume of a definite mass of gas?

(11)

A The force per unit area acting on it.

B Its temperature.

C The weight of the gas.

YOUR ANSWER --- B

This answer was obtained by multiplying 0.366 by 5 (for the 5 C° change) and then subtracting the product from 273.

This is not the correct procedure. The 0.366 cm^3 figure applies only to 100 cm^3 of a gas and should not be used here.

Think! A gas contracts 1/273 of its volume at 0° C for each C° drop in temperature. Use this information.

Please return to page 21 and select a better answer.

YOUR ANSWER --- B

You are correct. The 10-nt weight acts on 10 cm^2 of piston area, so that the pressure due to the weight is 1 nt/cm^2.

The atmosphere exerts an additional pressure of 10 nt/cm^2 on the top of the piston; hence the total pressure acting on the gas is 11 nt/cm^2.

Always remember to add atmospheric pressure to applied pressure, when the circumstances warrant it.

Next, let's perform a thought-experiment: suppose the piston in Figure 5 on page 105 is being moved downward by adding extra weights to the table. When the piston has descended to the half-way point, we stop adding weights. That is, we do this when the new volume of trapped air is exactly half the original volume. Originally a certain number of molecules were bombarding the piston, accounting for the pressure. After reducing the volume by half, there would be twice as many molecules bombarding the wall because the original number of molecules have been crammed into half the space. What do you think would happen to the pressure?

(5)

A The pressure would be reduced to one-half.

B The pressure would double.

C The pressure would remain the same.

YOUR ANSWER --- C

No. You are not clear about the difference between a direct and an inverse proportion. Be sure to review this in your notes. This review is important, so do it before returning to the original question.

Please return to page 79. Pick another answer.

ERIC

CORRECT ANSWER: The secret of success in the solution of these problems is the assignment of correct values to the symbols. In this problem, the volume into which the air will be compressed; hence, this is the new volume V'. The new pressure at the end of the process is 44.1 lb/in^2, so this is P'. The original pressure was normal atmospheric, or P = 14.7 lb/in^2. Finally, the unknown is the original volume, V. So:

$$PV = P'V' \text{ and } V = \frac{P'V'}{P} = \frac{44.1 \text{ lb/in}^2}{14.7 \text{ lb/in}^2} \times 2{,}250 \text{ cm}^3$$

$$V = \underline{6{,}750} \ \underline{\text{cm}^3}$$

Observe how we are able to mix metric and English units because we were consistent.

The effect of temperature on the volume of a gas has been previously noted: As the gas temperature rises, its volume tends to increase and vice versa. In 1787, Jacques Charles showed experimentally that <u>all gases expand the same amount when their temperature is raised 1 degree</u> provided, of course, that the pressure is held constant.

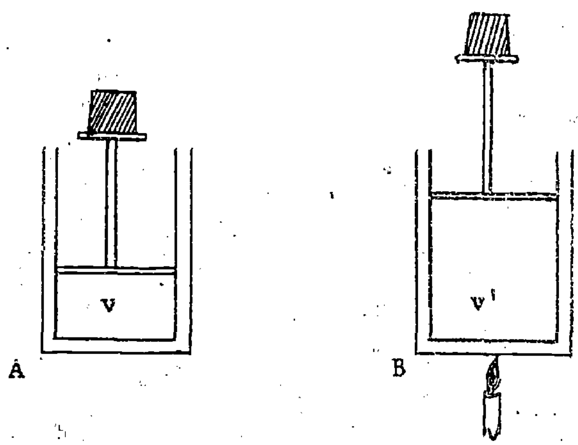

Figure 9

In Figure 9, the same cylinder of gas is shown in A at room temperature, and in B at some higher temperature after heating. In B, the volume of the gas has increased as a result of the increase in temperature. What can you say about the relative pressures in A and B?

(14)

A They are the same.

B. They are different.

ERIC

YOUR ANSWER --- A

If the number of molecules colliding with the right-hand wall, for instance, is greater than the number colliding with the left-hand wall in a given time, we could picture this as illustrated in Figure 2. (The wall areas are all equal; the container is a perfect cube.)

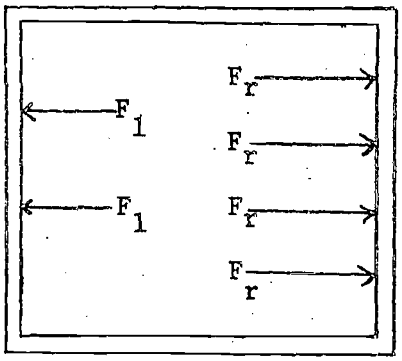

Figure 2

Each molecule, <u>on the average</u>, exerts the same force on the container walls. The total force on the right wall due to the sum of all the F_r's would be greater than the total force on the left wall, since there are more F_r's than there are F_l's.

Assuming the container is without inertia at the instant shown in the drawing, an unbalanced force would be exerted to the right and the container would tend to jump that way. The very next instant, the situation might be the reverse, causing the container to hop in the other direction. Thus, if the number of molecules colliding with each unit area on each of the four walls is <u>not</u> equal for a given period, the container tends to perform a random jig! Since no gas container has ever exhibited this tendency, we may conclude that the large number of molecules prevents this unevenness of collision from taking place.

Please return to page 3 and select the alternative answer.

YOUR ANSWER --- C

You are quite right. The volume of the gas is 273 cm^3 at 0° C. Since it contracts 1/273 of this volume for each degree drop in temperature, in going down to -5.00° C the contraction will be 5 times as large, or 5/273 of its original volume.

The total contraction is 273 x 5/273 = 5 cm^3. The new volume is, of course, the difference between the initial volume and the contraction or 273 cm^3 - 5 cm^3 = <u>268 cm^3</u>.

Similarly, the new volume at -10.0° C would be 10 cm^3 less than at 0° C, or 263 cm^3; at -20.0° C the volume will have become 253 cm^3; at -100° C the volume will have become 173 cm^3.

Here's an apparently silly question. Suppose you could continue to lower the temperature of the gas (originally 273 cm^3 at 0° C) to whatever figure you pleased. <u>What would the volume of the gas then be when it finally reached a temperature of -273° C?</u>

All right, let's see. Since the volume decreases 1/273 at 0° C for each degree of temperature reduction, then for 273 cm^3 of gas, the volume decrease would be:

$$\text{contraction} = 273\ cm^3 \times \frac{273}{273} = \underline{273\ cm^3}$$

However, if the initial volume was 273 cm^3 and the contraction is 273 cm^3, what volume would the gas have at this temperature?

Check your answer by turning to page 59.

YOUR ANSWER --- A

You are incorrect. Since we are dealing with 1,000 cm^3 of the gas, and since the temperature will be reduced 250 C^o, then the contraction can be computed from:

$$1,000 \text{ cm}^3 \times \frac{250}{273}$$

This answer is then subtracted from the original volume to find the new volume. The final answer is not 916 cm^3.

Repeat the calculation, find your error, then return to page 67 to select the right answer.

YOUR ANSWER --- B

Sorry, your answer is incorrect.

Figure 8 shows the actual products of the P and V values before rounding to two significant figures.

total P (nt/cm^2)	volume V (cm^3)	P x V
20.5	10.0	205.0
30.5	6.8	207.4
40.5	5.1	206.55
50.5	4.1	207.05
60.5	3.5	211.75

Figure 8

Admittedly, these products are not identical. But you must have noticed that they do not differ from each other by very much. Try rounding them back to two significant figures. What do you find?

This should give you food for thought. Remember that every experiment is likely to contain measurement errors due either to the crudity of the equipment or the inadequacy of the technician. Assuming that the technician in this case is competent, the equirpment could very easily cause the deviations noted in the products of PV.

Please return to page 23. Select the alternative answer.

YOUR ANSWER --- A

You are correct. We recommend the following symbols:

V = original volume ($600\ cm^3$)
V' = new volume (???)

P = original pressure (2 atm or $20\ nt/cm^2$)

P' = new pressure (3 atm or $30\ nt/cm^2$)

For the inverse proportion, $PV = k$, where P is any value of pressure (within limits) and V is the associated volume. Thus, $P'V' = k$, too, and we may then write $PV = P'V'$ which is the most convenient form of Boyle's Law. Solving this for V', the unknown:

$$V' = \frac{PV}{P'}$$

Substituting:

$$V' = \frac{2 \text{ atm} \times 600 \text{ cm}^3}{3 \text{ atm}} = \underline{400}\ \underline{\text{cm}^3}$$

Notice that the pressure units cancel out. Thus, you might have used the equivalents of 2 and 3 atm, respectively, namely $20\ nt/cm^2$ and $30\ nt/cm^2$ with no change in the answer. In fact, any pressure or volume units may be used as long as you are <u>consistent</u>.

<u>NOTEBOOK ENTRY</u>
<u>Lesson 14</u>

(Item 2)

(c) Boyle's Law is most conveniently expressed as:

$$PV = P'V'$$

where P = original pressure, V = original volume, P' = new pressure, V' = new volume. Any units may be used for pressure or volume as long as the same units are used throughout.

(d) Sample problem: (Copy the one we just solved.)

Please go on to page 53.

Let's try another problem involving Boyle's Law. (Use 1 atm = 14.7 lb/in^2.)

A tank contains 4.00 cubic feet of air at normal atmospheric pressure. Determine the pressure required to compress the air so that it occupies 1.00 cubic foot in (a) lb/ft^2; (b) cm of mercury; (c) nt/cm^2; and (d) atmospheres.

By including a request for one of the answers in lb/ft^2 and another in cm of mercury, we are not being unfair. If you understand the implications of the last part of Notebook Entry 2(c), you recognize that you can use any units you wish for volume and pressure provided that you use the same units throughout.

Find all four answers. Then examine the groups below. Only one of the groups contains all the correct answers. Can you pick it out?

Group 1	Group 2	Group 3
Pressure required	Pressure required	Pressure required
(a) 58.8 lb/in^2	(a) 40 lb/in^2	(a) 58.8 lb/in^2
(b) 300 cm of merc.	(b) 304 cm of merc.	(b) 304 cm of merc.
(c) 10 nt/cm^2	(c) 40 nt/cm^2	(c) 40 nt/cm^2
(d) 6 atm	(d) 4 atm	(d) 4 atm

(13)

A Group 1 is entirely correct.

B Group 2 is entirely correct.

C Group 3 is entirely correct.

D None of the groups is correct.

ERIC

YOUR ANSWER --- D

No, there's nothing wrong with this conversion:

$$
\begin{aligned}
{}^{o}K &= {}^{o}C + 273^{o} \\
&= -20^{o}\ C + 273^{o} \\
&= 253^{o}\ K
\end{aligned}
$$

Please return to page 10 and try again.

YOUR ANSWER --- A

To obtain this answer, you multiplied 3.66 by 5 (for the 5 C° change) and then subtracted the product from 273.

This is not the correct procedure. The 3.66 cm^3 figure applies only to 1,000 cm^3 of a gas and should not be used here.

You need to know that a gas contracts 1/273 of its volume at 0° C for each C° drop in temperature. That's all.

Please return to page 21. You can do better than this.

ERIC

YOUR ANSWER --- C

Reduction of the volume by half has not changed the number of molecules in the cylinder. They have been forced to occupy a smaller space, but we haven't allowed any to escape.

That means that there are more molecules colliding with the walls and with the bottom of the piston in a given interval of time. This is true, for the molecules are flying about in a smaller space, and each one has a shorter distance to go before colliding with a wall. If a given molecule doesn't fly far, it collides more often.

Since pressure is the net effect of these collisions, how can the pressure remain the same, if the number of molecule-to-wall collisions increases?

Please return to page 45 and select a better answer.

ERIC

YOUR ANSWER --- A

This is incorrect. Didn't you notice that the temperature was given in Centigrade? The temperatures T and T' must be expressed on the Kelvin scale. Your first step must be to convert both temperatures to Kelvin.

Please make the conversion and recalculate. Then return to page 40 and choose the correct answer.

YOUR ANSWER --- A

You are correct. Pressure is determined only by the total weight-to-area ratio of the piston assembly as shown in Figure 9 on page 47. Since this is unchanged, the pressure is constant.

Now, if the flame is removed from beneath the cylinder, the gas will slowly lose heat to the atmosphere, its temperature will fall, and when it reaches room temperature it will have contracted back to its original volume, V. In short, the volumetric change of a gas due to temperature changes is a two-way process.

Now, if a careful experiment is performed on a known volume of gas, say 1,000 cm^3--starting at 0^o C--we find that when the gas is cooled to -1.00^o C, it contracts to a new volume of 996.34 cm^3. (We assume that our measuring equipment is capable of giving this number of significant figures.) If the gas is further cooled to -2.00^o C, its volume becomes 992.68 cm^3. Upon further cooling to -3.00^o C, the volume shrinks to 989.02 cm^3. The cooling process may be continued to much lower temperatures with similar results. From the figures given above, how much does a volume of 1,000 cm^3 of gas contract for each C^o reduction of temperature?

(15)

A Neither of these is correct.

B 0.366 cm^3

C 0.0366 cm^3

CORRECT ANSWER: At -273° C, the volume of the gas would be zero!

If the volumetric contraction equals the initial volume, there would be no more gas left! The gas will have vanished! Now, on the face of it, this is an utterly ridiculous result, because matter cannot disappear into nothingness as a result of a temperature change. However, the explanation is quite simple.

The experimentally-obtained value for the contraction of a gas as obtained by Charles--0.00366 cm^3 per cubic centimeter of gas at 0° C, or 1/273 of the volume of a gas at 0° C--came out of measurements done on gases near room temperature. As a gas is cooled, it will ultimately reach a temperature at which it will liquefy. When in its liquid state, the contraction rate of the substance is no longer 1/273 of its volume at 0° C. In other words, if we could find a gas that remained a gas at any temperature, our results seem to indicate that its volume would become zero at -273° C. But all known gases liquefy before reaching this temperature, so we cannot cause matter to vanish by lowering its temperature.

Is the result we obtained by extrapolating real experiments into regions where they cannot possibly apply entirely meaningless, then? (Extrapolate--to carry beyond the limits of the experimental range; pronounced ek strap oh late). Not at all. It implies that nothing could ever become colder than -273° C. Other experiments of an entirely different nature point to the same lowest temperature for matter. For this reason, what do we call this temperature?

Try to think of the name, and then turn to page 89 to see if you're right.

YOUR ANSWER --- C

This is incorrect.

The absolute temperature of a given body does not determine whether energy will be transferred to it or from it. Energy transfer is dependent solely upon the difference of temperature that exists between bodies. So, it is wrong to say that the degree of coldness will prohibit energy transfer.

Please return to page 14. One of the other answers is much better then this one.

ERIC

YOUR ANSWER --- A

You are correct. Contraction per degree is found by subtracting one volume from another. Thus:

t (^oC)	volume (cm^3)	contraction (cm^3)
0	1,000	----------
-1.00	996.34	3.66
-2.00	992.68	3.66
-3.00	989.02	3.66

So, if you start with 1,000 cm^3 of any gas at 0^o C, it contracts 3.66 cm^3 for each Centigrade degree of temperature reduction.

As a matter of simple arithmetic, what fractional part of 1,000 cm^3 is 3.66 cm^3?

(16)

A $\frac{366}{1,000}$

B $\frac{1}{366}$

C $\frac{1}{273}$

D None of these.

YOUR ANSWER --- B

Sure! You're correct. You know that heated objects expand and cooled objects contract. A gas does not differ from a solid or liquid in this respect. Its volume will change with changes of temperature.

So, we must be careful in stating Boyle's Law, to include something about temperature, because this, too, can cause volume changes.

NOTEBOOK ENTRY
Lesson 14

2. Boyle's Law

(a) The volume occupied by a confined gas is inversely proportional to the pressure exerted on it, if the temperature of the gas is held constant.

$PV = k$ if temperature is constant.

(b) Boyle's Law applied to real gases more accurately when the gas is at low pressure. At high pressures, Boyle's Law becomes approximate and ultimately does not apply.

A few numerical problems will help you achieve a "feel" for Boyle's Law. Here's a simple one:

A confined gas has a volume of 600 cm^3 at a pressure of 2.0 atmospheres (20 nt/cm^2). Provided there is no change of temperature, what volume will the gas occupy at 3.0 atm?

(12)

A 400 cm^3

B 300 cm^3

C Neither of the above is correct.

YOUR ANSWER --- A

You are correct. Refer to Figure 12 on page 33. Where the C curve starts at -273° C, the K curve starts at 0° K, which is the same temperature (absolute zero). The C curve meets the y-axis at 0° C, and the K curve meets it at $+273^{\circ}$ K, again the same temperature. The slopes of the curves are identical, and the degree size for both the C and K scales are the same; hence the only change made is a shift of the x-axis.

We shall use the symbol T for temperatures on the Kelvin scale. At point 1 (on curve B) the volume of the gas is V and the Kelvin temperature is T. At point 2, the Kelvin temperature has been halved. The resulting volume is then V/2. At point 3, where the temperature has been reduced to T/4, the volume is V/4. Since the origin of the axis is zero for both V and T, what does this relationship permit us to state?

(22)

A The volume of a gas is equal to its Kelvin or absolute temperature.

B The volume of a gas is inversely proportional to its Kelvin or absolute temperature.

C The volume of a gas is directly proportional to its Kelvin or absolute temperature.

YOUR ANSWER --- B

You are correct. Body A is at absolute zero; there is no lower temperature. For heat to flow from A into some other body, the other body must be at a lower temperature than A. Hence, it is impossible for heat to flow from A into any other body.

This brings us at last to an acceptable definition of absolute zero. Let's make it a notebook entry to conclude the formal part of this lesson.

NOTEBOOK ENTRY
Lesson 14

5. Absolute Zero

(a) A body is at a temperature of absolute zero when its internal energy cannot be transferred to any outside body regardless of the temperature this outside body may have.

(b) The value of absolute zero on the three common temperature scales is:

Kelvin...............	0.00° K
Centigrade..........	-273.16° C
Fahrenheit..........	-459.69° F

Before continuing, please turn to page 125 in the blue appendix.

ERIC

YOUR ANSWER --- B

This conclusion is unwarranted. If V decreases as P increases, we may very possibly be dealing with an inverse proportion between these variables. However, the variation we have described so far does not assure us that V is inversely proportional to P.

total P (nt/cm^2)	volume V (cm^3)
20.5	10.0
30.5	6.8
40.5	5.1
50.5	4.1
60.5	3.5

Figure 7

To determine this, we must extend our investigation of the results in Figure 7, which is a copy of the last two columns of Figure 6 on page 71.

So please return to page 90 and choose the alternative answer.

YOUR ANSWER --- B

You are correct. An unequal number of collisions of molecules against different walls per unit time would develop unbalanced forces that would make the container do a random jig. Since no container has ever been known to do this, we may conclude that any molecule-to-wall collision inequalities that do exist tend to average out, due to the large number of molecules in motion.

A valuable point emerges from all this: the random motion of the molecules of a gas accounts for the force exerted on the container walls from within. The force arises from collisions between the molecules and the confining walls, and we may assume that equal number of molecules strike equal areas in equal times.

Suppose the container in Figure 3 is fitted with two frictionless pistons, Piston 1 having 5 times the surface area of Piston 2.

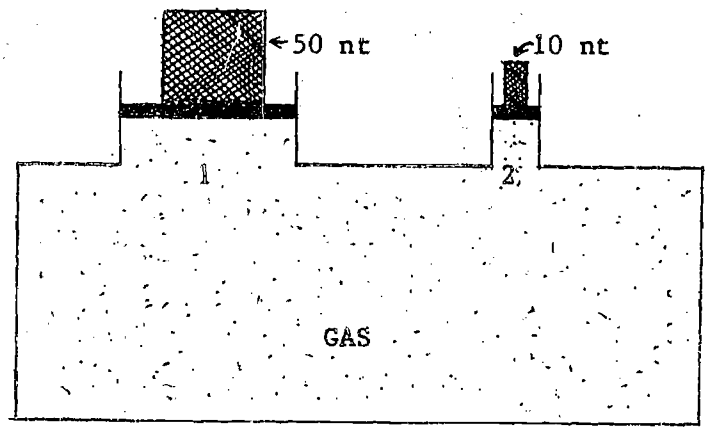

Figure 3

The container is filled with gas, a 50-nt weight is placed on the larger piston, and a 10-nt weight on the smaller piston. Of course, both weights would push the pistons down slightly, compressing the gas a bit. What would happen immediately after this initial compression?

(2)

A Piston 1 would move down and Piston 2 would move up.

B Piston 1 would move up and Piston 2 would move down.

C The system would be in equilibrium.

ERIC

Just for fun, try this one: A cylinder-piston container holds 1,000 cm^3 of helium at 0^{o} C and normal atmospheric pressure. If the temperature is lowered to -250^{o} C <u>with no change of pressure</u>, what volume will the helium then occupy?

(18)

A 916 cm^3 (approx.)

B 91.6 cm^3 (approx.)

C 84.0 cm^3 (approx.)

D None of these is correct.

ERIC

YOUR ANSWER --- D

You are correct. The right answer is $\underline{2.22 \times 10^3 \text{ liters}}$.

$P = 760$ mm
$V = 2.00 \times 10^3$ l
$T = 273^\circ$ K

$P' = 735$ mm
$V' = ???$
$T' = 293^\circ$ K

The equation

$$V' = V \times \frac{P}{P'} \times \frac{T'}{T}$$

$$V' = 2.00 \times 10^3 \text{ l} \times \frac{760 \text{ mm}}{735 \text{ mm}} \times \frac{293^\circ \text{ K}}{273^\circ \text{ K}}$$

$$V' = \underline{2.22 \times 10^3 \text{ liters}}.$$

Now let's move on to further discussion of the kinetic theory.

Please turn to page 124 in the blue appendix.

ERIC

In Notebook Entry 3(c) you will find our first tentative statement about the meaning of absolute zero. We said that absolute zero, which is -273° C or 0° K, is the lowest temperature to which matter can be cooled. Remember that we arrived at this particular temperature by extrapolating the cooling curve of a gas beyond the region where it actually remains a gas. Now we approach this from another point of view.

When a substance is cooled, what happens to the average speed of its atoms or molecules?

(26)

A The average speed increases.

B The average speed decreases.

C The average speed remains the same.

ERIC

YOUR ANSWER --- A

You are correct. To find the pressure of the gas, we must know the total force acting on it.

There are three contributing factors:

(1) The weight of the objects we lay on the piston table. We can choose any value for these.
(2) The pressure of the atmosphere. This is to be taken as 10 nt/cm^2.
(3) The weight of the piston-rod-table assembly, since it also presses down on the gas and contributes to the final pressure.

Please continue by turning to page 71.

ERIC

The tabulated data obtained from an actual laboratory exercise is given in Figure 6. Study this table. Try to see how all the figures were obtained.

Preliminary data: Piston area = 10 cm^2
Weight of piston assembly = 4.0 nt
Atmospheric pressure = 10.1 nt/cm^2

Trial	weight on table (nt)	total weight (nt)	pressure due to wts (nt/cm^2)	total P (nt/cm^2)	volume V (cm^3)
1	100	104	10.4	20.5	10.0
2	200	204	20.4	30.5	6.8
3	300	304	30.4	40.5	5.1
4	400	404	40.4	50.5	4.1
5.	500	504	50.4	60.5	3.5

Figure 6

In Trial 1, a 100-nt weight has been placed on the table. Since the piston assembly weighs 4.0 nt, the total weight in this trial is 104 nt. The piston area = 10 cm^2; hence the pressure due to the weight is $P = F/A = 104\ nt/10\ cm^2 = 10.4\ nt/cm^2$.

The next column for Trial 1 displays a figure of 20.5 nt/cm^2. How was this value for the total pressure obtained?

(7)

A By dividing the volume (10.0 cm^3) by 0.488.

B By using a pressure-measuring instrument.

C By multiplying the 100-nt weight by 0.205.

D By adding the atmospheric pressure to the pressure due to the weights.

YOUR ANSWER --- B

On the face of it, merely by inspection, you can tell that this answer is impossible.

The gas is being heated; it will therefore expand and increase its volume if the pressure is constant. But 468 cm^3 is smaller in volume than 500 cm^3, so you must have inverted the relationship.

From Charles' Law, we know that

$$\frac{V}{T} = \frac{V'}{T'}$$

$$\text{so } V' = \frac{VT'}{T}$$

Remember, too, that Charles' Law works only when Kelvin temperatures are used for T and T'.

Please return to page 40 and pick a more reasonable answer.

YOUR ANSWER --- A

Really! We're surprised at you!

Force per unit area is pressure, so it is not something in addition to pressure.

Be careful! Be sure to remember the definitions of terms.

Try again. Please return to page 43 and select another answer.

ERIC

YOUR ANSWER --- B

No, the slopes in A and B of Figure 12 on page 33 are the same.

A way to prove this is to measure the angle made by the cooling curve with either the y- or the x-axis angle. You will find both angles to be equal.

Remember, slope is defined:

$$\text{slope} = \frac{\Delta y}{\Delta x}$$

If the curves are parallel to each other, then the $\frac{\Delta y}{\Delta x}$ values for both are the same.

Please return to page 33 and read the answers carefully. Refer to the curves and then choose a better answer.

ERIC

YOUR ANSWER --- B

If V were inversely proportional to T, would not the magnitude of V increase as T was decreased? Remember this happened when we investigated the effect of pressure on volume. As pressure on a gas is raised, its volume decreases; thus, volume is inversely proportional to pressure, by Boyle's law.

But is that happening here? No, it is not.

Please return to page 63. The answer should now be obvious.

ERIC

YOUR ANSWER --- A

Reivew your notes for Lesson 13. You have forgotten some very essential concepts of the kinetic theory.

Remember that according to the kinetic theory, temperature is a measure of the average kinetic energy of the molecules of a substance (item 3(a) for Lesson 13).

Since kinetic energy is related to the mass and speed of the molecule, that is, K.E. = $\frac{1}{2}mv^2$, and since molecular mass does not change with temperature, then it is the speed that must change.

So, we might then say if there is an increase in temperature for any given sample of a substance, there is likely to be an increase in the molecular speed. Naturally, we are aware of the fact that when a substance changes its state, a possible change of internal potential rather than kinetic energy may occur. In general, however, if we exclude such special occurrences, what happens to the average speed of the molecules of a substance when it is cooled?

Please return to page 69 and select the correct answer.

YOUR ANSWER --- A

This is incorrect. The total <u>force</u> acting downward on the piston due to the weight is 10 nt (ignoring the piston's weight). To this you added the atmospheric <u>pressure</u> of 10 nt/cm^2. You added two different kinds of quantities. This is never permissible! What is the sum of 6 apples and 3 oranges? Would you say it is 9 apple-oranges? The process of addition always requires that the quantities being added represent the same physical objects or measurements. We are looking for the pressure exerted on the gas.

Please return to page 105 and select a better answer.

YOUR ANSWER --- A

Remember heat is a flow of energy from one body of higher temperature to another body of lower temperature. Here the requirements for a flow of heat are fulfilled because body B is at 0.00001° K and body A is at 0.00000° K. Despite the extremely low temperatures of both bodies, there is a temperature differential and heat may be expected to flow from body B to body A. This answer is correct in stating that heat will flow from body B to body A.

However, it is incorrect to state that the heat will flow until both bodies are at 0.00000° K. For if a flow of heat does take place from B to A the energy thus gained by A will tend to raise its temperature above absolute zero. Thus, both bodies cannot end with 0.00000° K.

The right answer should now be obvious. Please return to page 14 and select it.

YOUR ANSWER --- A

You are correct. When two variables are directly proportional, an increase of one of them will cause an increase of the other. If any proportion exists at all, it will have to be of inverse nature.

Let's check the tabulated data in Figure 7 to determine if they are inversely proportional.

total P (nt/cm^2)	volume V (cm^3)
20.5	10.0
30.5	6.8
40.5	5.1
50.5	4.1
60.5	3.5

Figure 7

If you have forgotten how to check a series of related values for a pair of interdependent variables to see if an inverse proportion exists, refresh your memory by consulting your notebook. When you are ready, choose the one true statement below.

When are two variables inversely proportional?

(9)

A If their sum is a constant.

B If their difference is a constant.

C If their ratio is a constant.

D None of these is correct.

YOUR ANSWER --- C

If this equation is correct, you will get an answer of 273° when you substitute the temperature of boiling water, 100° C for $^{\circ}$C, and 373° K for $^{\circ}$K, and add them.

But you don't, do you? Thus, the equation is not right.

Think this over. Now choose the right answer. Please return to page 32.

YOUR ANSWER --- B

On the contrary, this conversion is quite all right:

$$
\begin{aligned}
{}^{o}K &= {}^{o}C + 273^{o} \\
&= 14^{o}\ C + 273^{o} \\
&= 287^{o}\ K
\end{aligned}
$$

Please return to page 10. Carefully select another answer.

YOUR ANSWER --- B

Quite right. Pressure is force per unit area. To determine pressure P from total force F and area A, you simply divide F by A. Thus, in Figure 3 on page 66, suppose that the area of Piston 1 is 5 cm^2 so that the area of Piston 2 is 1 cm^2. Once both pistons have settled so equilibrium is established, we can summarize the conditions in this manner: (1) The pressure of the gas is 10 nt/cm^2 because the upward force on this piston must be 50 nt to hold the 50-nt weight in equilibrium by the gas pressure. The area of the piston is 5 cm^2 and, with a pressure of 10 nt/cm^2, the total force acting upward is $F = PA = 10\ nt/cm^2 \times 5\ cm^2 = 50\ nt$.

(2) If the 10-nt weight is also held in equilibrium by the gas pressure of 10 nt/cm^2 and the area of the piston is 1 cm^2, then the total force in this case is $F = PA = 10\ nt/cm^2 = 10\ nt$. The upward force obviously keeps the 10-nt weight in equilibrium.

NOTEBOOK ENTRY
Lesson 14

1. Pressure

(a) Pressure is defined as force per unit area, or $P = F/A$.

(b) Pressure is often measured in nt/cm^2. Although this is not strictly MKS, it is quite common. In the MKS system pressure is measured in nt/m^2.

(c) The pressure of a gas is due to the resultant force of many random moving molecules on the walls of the container. The average pressure on all the walls and throughout the body of the gas is uniform.

Please turn to page 83.

ERIC

To continue our study of pressure in confined gases, let's review briefly some information pertaining to atmospheric pressure.

The blanket of air covering the Earth has weight; consequently, the air exerts pressure on bodies at the surface of the Earth. This pressure varies from day to day and from place to place. However, an average or standard value for normal atmospheric pressure has been established by common consent. You are probably familiar with the value of 15 lb/in^2, (or, more exactly, 14.7 lb/in^2) as one standard atmospheric pressure. This pressure is also called <u>one atmosphere</u>.

In a mercury barometer (Figure 4), one atmosphere of pressure can support a column of mercury 76 cm high.

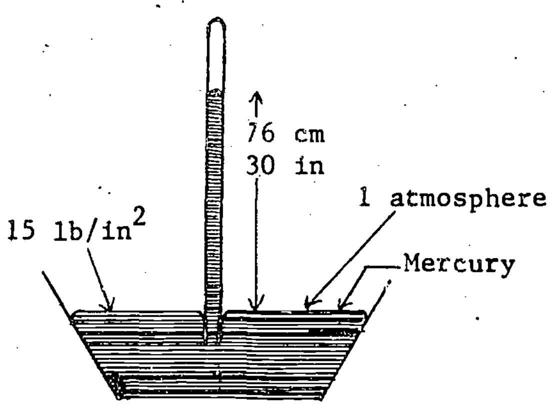

Figure 4

So, when the weather report says that the air pressure is 76 cm of mercury, or 30 inches of mercury, you must translate this to 14.7 lb/in^2. Although "cm (or inches) of mercury" is not, strictly speaking, a unit of pressure, it is commonly used as such.

Pressure given in any one unit is always proportional to the pressure in any other unit. For example, a pressure of 0.5 atmosphere = 7.5 lb/in^2 = 15 inches of mercury = _______ cm of mercury.

Write the answer; then please turn to page 105.

ERIC

YOUR ANSWER --- B

You are correct. Although one body is at absolute zero and the other very close to it, there is a temperature difference, and a flow of heat from the body with the higher temperature to the body with the lower temperature is expected. This flow will continue until the differential vanishes. This can occur only when body A has risen slightly in temperature, and when the temperature of body B has fallen slightly to meet it. When the temperatures are the same, the flow of heat ceases.

Now, here is the basis of our reasoning. Is it possible, under any conceivable conditions, for heat to flow out of body A (remember its temperature is 0.00000° K) into any other outside body? That is, can we set the temperature of any other body so that heat will flow out of body A into it?

(29)

A Yes.

B No.

C I don't know.

ERIC

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YOUR ANSWER --- D

This answer is incorrect. Let's check some facts.

The solution of a problem involving Boyle's Law requires that you know at least 3 of the 4 quantities, the fourth being the unknown.

In this problem the known quantities are:

original volume = V = 4.00 ft^3
original pressure = P = 1 atm
new volume = V' = 1.00 ft^3
while the unknown is P' = ???

You know that any units may be used for P and V, as long as the same units are used for P' and V' respectively. Since P is initially given as 1 atm, use this unit first; then repeat the problem using 14.7 lb/in^2, 76 cm of mercury, and 10 nt/cm^2 in turn.

The fundamental equation is: $PV = P'V'$

and since P' is wanted, then: $P' = \frac{PV}{V'}$

So, the first substitution would look like this:

$$P' = \frac{1 \text{ atm} \times 4.00 \text{ ft}^3}{1.00 \text{ ft}^3}$$

All right? Now correct your previous errors, return to page 53, and choose another answer.

YOUR ANSWER --- A

You're trying to set up some sort of direct proportion.

First, remember that halving the trapped gas volume does not change the number of gas molecules in the cylinder. If they are packed into a smaller space, each one, in its random travels, covers a shorter distance before colliding with a wall or another molecule. It seems reasonable that such collisions will occur more often in the smaller space.

If pressure is the net effect of molecule-to-wall collisions, you cannot conclude that the pressure would go down as a result of an increase in the number of collisions.

Please return to page 45. Select the right answer.

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ERIC

CORRECT ANSWER: The temperature -273° C is called absolute zero. There is much evidence to show that matter cannot be driven to any temperature lower than this.

In extrapolating the contraction of a gas to absolute zero as we did a few moments ago, we started with 273 cm^3 of the gas to keep our arithmetic simple. Perhaps you feel that it is unfair to reach a conclusion when the basis of the experiment is a very special volume. That is, does -273° C turn out to be absolute zero when we repeat the same experiment with some other volume?

Please turn to page 98 and see if you are right.

YOUR ANSWER --- D

You are correct. The atmospheric pressure is 10.1 nt/cm^2. This is added to the pressure of the weights, 10.4 nt/cm^2, so that the total pressure on the gas, P, is 20.5 nt/cm^2. Identical procedures have been followed for the other four trials. From now on, we will work with only the last two columns of Figure 6 on page 71, which represent our "working data."

From Trial 1 to Trial 5, the pressure rises steadily. Simultaneously, the corresponding volume decreases consistently. The moment we recognize this, we know positively that:

(8)

A We are not dealing with a direct proportion between P and V.

B We are not dealing with an inverse proportion between P and V.

ERIC

YOUR ANSWER --- C

You are correct. The force exerted by gas molecules is equal for equal areas as we demonstrated previously. Therefore, every square cm of Piston 1 has the same upward push from the gas as every square cm of Piston 2.

However, in Figure 3 on page 66, Piston 1 has an area of 5 times as many square cm; hence the upward force on it is 5 times as great as that on Piston 2. Since the downward force on Piston 1 (50 nt) is 5 times as great as that on Piston 2 (10 nt), there are no unbalanced forces, and the system is in equilibrium.

Now, considering only the force exerted by the gas on the pistons, let's distinguish between the <u>total force</u> and the <u>force per unit area</u>. The total force exerted by the gas on Piston 1 is 5 times as great as the total force on Piston 2, but <u>the force per unit area is exactly the same on</u> each. The force per unit area is called <u>pressure</u>. If pressure is expressed by P, force by F, and area by A, which of the following relationships correctly defines <u>pressure</u>?

(3)

A None of these is correct.

B $P = \frac{F}{A}$

C $P = \frac{A}{F}$

D $P = F \times A$

ERIC

YOUR ANSWER - D

You're wrong.

One of the answers given is correct.

Remember:

(1) From Charles' Law, you can write

$$\frac{V}{T} = \frac{V'}{T'}$$

from which you can obtain

$$V' = \frac{VT'}{T} \qquad (2)$$

Then, if you express the temperatures in Kelvin degrees, you will arrive at one of the answers listed. Be sure you make the conversion to Kelvin degrees correctly.

Please return to page 40 after you have recalculated. You can find the right answer in the list.

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YOUR ANSWER --- C

No. You've slipped!

A given mass of gas has a fixed weight (provided, of course, that we keep it in a definite location where gravity doesn't change). If the mass is given, weight is not a variable and therefore the volume does not depend on it. Remember, in the sense we are using it, the word "depend" and its synonyms relate to the variation of one quantity as a function of another.

Please return to page 43. There is a better answer you can pick.

ERIC

YOUR ANSWER --- C

Well, let's check some facts:

(1) By definition, body B has a higher temperature than body A, if heat will flow from body B to body A.

(2) Similarly, in order for heat to flow out of body A at absolute zero into Body B at some other temperature, then body A must be at a higher temperature than body B.

(3) But if absolute zero is the lowest possible temperature, how can body A at 0.00000° K be at a higher temperature than some other body?

(4) Hence, heat cannot flow out of body A at absolute zero into any other body regardless of its temperature.

Please return to page 84 and choose the right answer.

YOUR ANSWER --- A

You cannot test proportionality of any kind by comparing the sums of pairs of values for two interdependent variables.

Please return to page 79. Before making your next selection, please check your notes and give the question some additional thought.

ERIC

The best way to test this problem is to construct a graph starting with some random volume other than 273 cm^3. (Figure 10)

	t (^oC)	V (cm^3)	CONT. (cm^3)	V' (cm^3)
	0	100		
(1)	- 50	100	18.3	81.7
(2)	- 100	81.7	18.3	63.4
(3)	- 150	63.4	18.3	45.1
(4)	Liquefies			

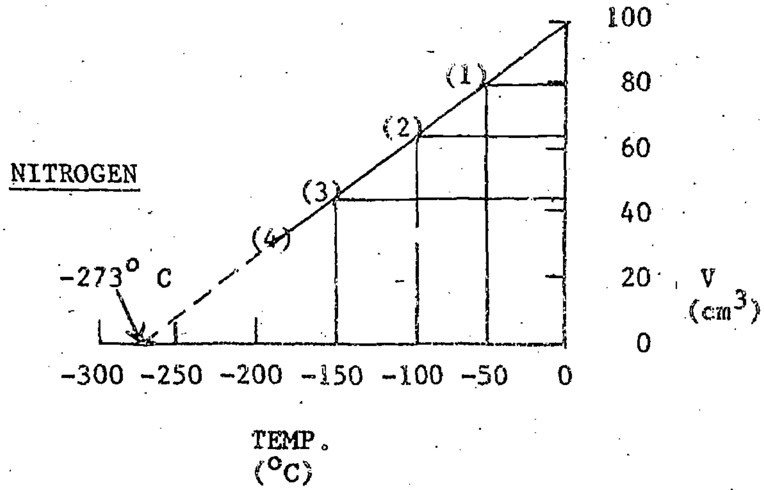


Figure 10

In this experiment we used nitrogen starting at 0° C with a volume of 100 cm^3. Referring to the table, you can see that if we lower the temperature of 100 cm^3 of the gas from 0° C to -50.0° C, then the contraction is 100 cm^3 x 50/273 = 18.3 cm^3. So, at -50.0° C, the volume has shrunk to 81.7 cm^3. (Point 1 on the graph.) The other points are obtained in a similar fashion. Since nitrogen liquefies at -196° C, the solid part of the curve ends at point (4). When the curve is extrapolated to the x-axis (zero volume or the vanishing point), absolute zero again turns out to be ______° C. Fill in the number; then turn to page 106.

YOUR ANSWER --- C

We're not quite sure what you mean by "minus and plus" curves. Regardless of our choice of axis, both curves slope to the right as the ordinate values go up. Thus, you cannot differentiate between them by calling one "minus" and the other "plus." It is true that in A, temperatures are minus values, and in B they are plus values. This is caused by the difference in temperature scales, not by any difference in curves.

Please return to page 33. Choose a better answer.

ERIC

YOUR ANSWER --- A

We believe that you chose this answer by misinterpreting the following facts:

When the temperature is	Then the volume is
T	V
$\frac{1}{2}$T	$\frac{1}{2}$V
$\frac{1}{4}$T	$\frac{1}{4}$V

Because of the similarity of form between the factors in the two columns, you thought that the volume is equal to the temperature.

The temperature T is 273° K. At that temperature, the volume could be anything, depending entirely on the initial amount of gas. The relationships above merely say that when the temperature is halved, the volume is halved; when the temperature is reduced to $\frac{1}{4}$, the volume drops to $\frac{1}{4}$. This does not mean an equality of T and V.

Please choose another answer after returning to page 63.

YOUR ANSWER --- C

You are correct. From Charles' Law we have: $V' = \frac{VT'}{T}$. Converting the two temperatures to Kelvin, we then can write:

$$V' = 500\ \text{cm}^3 \times \frac{313^\circ\ \text{K}}{293^\circ\ \text{K}}$$

$$V' = \underline{534}\ \underline{\text{cm}^3}$$

Often both temperature and pressure change simultaneously. This means that Boyle's Law and Charles' Law must be applied simultaneously. Let us write both laws in the familiar proportionality form:

Boyle's Law: $V = \frac{k}{P}$ if T is constant

Charles' Law: $V = k'T$ if P is constant

We may combine these into a single proportion: $V = k''\frac{T}{P}$ in which k" is some constant derived from the other two, k and k'.

Solving for this constant, we then have: $k'' = \frac{PV}{T}$

Since, for a given sample of gas, the fraction PV/T will yeild the same numerical value for all associated values of P, V, and T, which of the following would be a convenient form for expressing this relationship?

(24)

A $\frac{PV}{T} = \frac{P'V'}{T'}$

B $\frac{PT}{V} = \frac{P'T'}{V'}$

C $PVT = P'V'T'$

YOUR ANSWER --- B

You are correct. We can depend on this effect as long as the substance is in a temperature range where it does not change its state. So, let's confine ourselves to gases in the Boyle's Law temperature range.

When a gas is cooled, its temperature is reduced either by allowing heat to flow out of it into some body at a lower temperature, or by allowing it to expand to do external work. In either case, we believe that the average speed of the random, vibratory motion of its molecules decreases. The molecules move more slowly, undergo less violent collisions, and exert a smaller average pressure on the walls of the container. It seems reasonable, therefore, to associate lower and lower temperatures with slower and slower molecular motion. It seems equally reasonable to think when a gas is finally cooled to absolute zero (if this could ever be done), the molecular motion would cease altogether.

This idea seems logical. Absolute zero is the lowest possible temperature to which the gas can be cooled; the slowest possible molecular motion is, obviously, no motion at all. Hence, the ideas seem to dovetail nicely.

Please turn to page 103.

ERIC

However, to reach these conclusions we must extrapolate the behavior of gases beyond the point where the substance remains a gas. To liquefy, the gas molecules form bonds that move them much closer together; to solidify, strong bonds must form that further decrease the distance between the molecules. At this point, the molecules cannot move about with anything like the freedom they have in the gaseous state.

Today physicists believe that molecular motion continues when a substance is brought down to absolute zero, even in theory; and that absolute zero represents a temperature of least molecular motion, but not zero molecular motion. Extrapolating to absolute zero, then, does not mean quite the same thing as extrapolating to absolute rest. Absolute zero cannot be defined as the temperature at which all molecular motion ceases.

How can we improve the tentative definition of absolute zero given in Notebook Entry 3(c) of the previous lesson? Absolute zero "is the lowest temperature to which matter can be cooled," is not a significant statement. We ought to be able to do better than that.

Please continue to page 104.

ERIC

All right, let's work from the point of view of internal energy. Bearing in mind what we have just said, which of the following statements is true?

(27)

A A body at absolute zero has no internal energy.

B A body at absolute zero has very little internal energy.

C A body at absolute zero has no potential energy, but does have some internal kinetic energy.

D A body at absolute zero has no internal kinetic energy, but does have some internal potential energy.

CORRECT ANSWER: A pressure of 38 cm of mercury is the equivalent of 0.5 atm, or 7.5 lb/in^2, or 15 inches of mercury.

Before continuing, please turn to page 123 in the blue appendix.

In performing experiments with gas pressures, always remember that atmospheric pressure must be taken into account in recording and using the data. Figure 5 shows this.

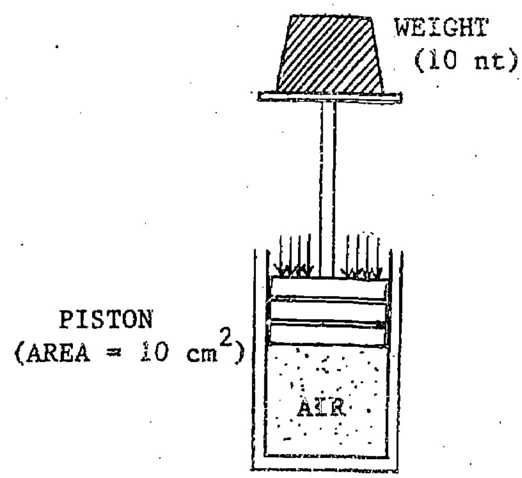


Figure 5

Here a gas-tight, frictionless piston is fitted inside a smooth cylinder of glass, trapping a volume of air. A 10-nt weight rests on the piston table, and the face area of the piston is 10 cm^2. Atmospheric pressure, shown by the short arrows over the piston, is taken as 1 atmosphere, or 15 lb/in^2. Note: 15 lb/in^2 is roughly the same as 10 nt/cm^2.

Look at the diagram and the numerical data; then assuming that the piston has reached equilibrium, find the pressure exerted on the gas. This answer will also represent the pressure exerted by the gas on the piston, since the system is in equilibrium.

(4)

A 20 nt/cm^2

B 11 nt/cm^2

C 10 nt/cm^2

D 1.0 nt/cm^2

CORRECT ANSWER: Extrapolation of the nitrogen cooling curve for a random volume of the gas shows that absolute zero is -273° C.

Time for a Notebook Entry.

NOTEBOOK ENTRY
Lesson 14

3. Expansion and Contraction of Gases

(a) An ideal gas expands or contracts 0.00366 cm^3 for each degree change of temperature, regardless of its composition. Real gases follow this law approximately.

(b) Another way to describe the rate of volumetric change of a gas is to say that its volume changes 1/273 of the volume at 0° C for each degree change of temperature Centigrade.

(c) An ideal gas (one which does not liquefy regardless of temperature) would, therefore, shrink to zero volume at a temperature of -273° C. This temperature is called absolute zero; it represents the lowest temperature to which matter can be cooled.

(d) Real gases liquefy before they reach absolute zero. An extrapolation of the cooling curve of a real gas meets the zero-volume axis at -273° C. At normal atmospheric pressure, the liquefaction temperatures of some common gases are:

Nitrogen..............	-196° C
Oxygen...............	-183° C
Hydrogen..............	-253° C
Helium...............	-269° C
Argon................	-186° C
Neon.................	-246° C

As you will notice, helium approaches absolute zero most closely before it liquefies. This is one of the things which explains the importance of helium in the science of cryogenics, or low-temperature physics. Please continue by turning to page 67.

YOUR ANSWER --- C

From a strictly numerical point of view, it is quite possible to obtain an answer of 20.5 by multiplying 100 by 0.205. But how does this apply to the question? You should be able to explain all your operations before you do them.

The values in the fifth column are important one; they were obtained by performing a logical arithmetical process based upon physical considerations. Please think about this, then return to page 71, and select the answer which results from this logical operation.

ERIC

YOUR ANSWER --- C

You are incorrect.

Perhaps it would be helpful to verbalize the expression $PV/T = k$. It would sound like this: given a certain volume of gas at a pressure P and an absolute temperature T, we multiply the pressure and volume (PV) and divide this product by the absolute temperature (PV/T). From this we obtain a certain number. Next, we allow both the pressure and temperature to change to some new values, say P' and T'. We now measure the new volume V', and again perform the multiplication P'V' and the division (P'V'/T'). The new number obtained therefrom will be the same as the number obtained when we originally performed the arithmetic operation.

A given sample of gas, the pressure and temperature of which are changed from one set of values to another, will change its volume so that the product of pressure and volume divided by the temperature will yield the same number as it did before the change.

Please return to page 101. The correct answer should be clear now.

YOUR ANSWER --- C

To find the contraction for each degree, you subtract the volume at -1.00° C from the volume at 0° C; you repeat the subtraction of volumes for the other temperatures, subtracting the volume at -2.00 degrees from that at -1.00 degree, and the volume at -3.00 degrees from that at -2.00, and so forth.

In other words, the contraction of a gas per degree Centigrade is simply the difference between the two volumes at the initial and final temperatures.

The answer you selected indicates that you performed this subtraction incorrectly.

Please be careful. Write the figures down, then subtract. Please return to page 58 and choose another answer.

YOUR ANSWER --- B

No, your answer is incorrect.

Consider how we can estimate the pressure of a gas in a piston-cylinder arrangement such as that in Figure 9 on page 47. In A, the pressure of the gas is determined by the sum of the weights (piston assembly and the added weight on the table) divided by the area of the piston.

Now look at B. The volume of the gas has increased, but how about the sum of the weights and the area of the piston? Have these changed? Since they are the same in B as in A, we are forced to conclude that the gas pressure has been held constant during the heating process.

Please return to page 47 and choose the other answer.

ERIC

YOUR ANSWER --- B

You are correct. The frequency of molecule-to-wall collisions would certainly increase, causing the pressure to increase. Furthermore, it is reasonable to guess that halving the volume would double the pressure, all other things remaining equal. This is only a guess, however, unless we prove it.

Obviously, an actual experiment is in order to enable us to find a numerical relationship between pressure and volume, if one exists. If the cylinder in Figure 5 on page 105 is marked off in cubic centimeters, we can then find the volume of the trapped gas directly. We can add known weights to the piston table, wait for equilibrium, and so determine the pressure needed to establish each new volume.

Since we are going to do an actual experiment, will we need to know the weight of the piston-rod-table assembly before we start?

(6)

A Yes.

B No.

ERIC

YOUR ANSWER --- C

This answer is incorrect.

You may have been thinking about change of state. When a substance is cooled through a temperature interval where it is, for example, solidifying from the liquid state, there may be no change of average molecular speed, because the potential energy, rather than the average kinetic energy of the molecules is changing.

Let's eliminate change of state from this problem. For when a gas is cooled in the temperature range in which Boyle's Law applies where it remains a gas at all times, there is no change of state involved.

Under these conditions, when a substance is cooled, what happens to the average speed of its molecules?

Please return to page 69 and pick a better answer.

YOUR ANSWER --- C

You are correct. The easiest way to do this is shown below:

$V = 4.00\ ft^3$
$P = 1.00\ atm$
$V' = 1.00\ ft^3$
$P' = ???$

$$P' = \frac{PV}{V'} = \text{[illegible]} \times \frac{4.00\ ft^3}{1.00\ ft^3} = \underline{4\ atm}$$

Observe that P' is going to be 4 times as large as P, <u>regardless of units</u>. Thus, you can at once write your answers:

(a) $14.7\ lb/ft^2 \times 4 = 58.8\ lb/ft^2$
(b) 76 cm of mercury x 4 = 304 cm of mercury
(c) $10\ nt/cm^2 \times 4 = 10\ nt/cm^2$
(d) 1 atm x 4 = 4 atm.

Here's one more problem involving the application of Boyle's Law. The tire of a motor scooter has an internal volume of $2{,}250\ cm^3$. It is pumped up with air to a pressure of $44.1\ lb/in^2$. What volume of air at normal atmospheric pressure ($14.7\ lb/in^2$) is required to accomplish this?

Write out your solution. Be careful with the values you assign to V, P, V', and P'. When you have your answer, turn to page 47.

ERIC

YOUR ANSWER --- A

This is incorrect. One of the expressions is right.

Pressure is force per unit area. If a force of 12 nt is exerted on 4 cm^2 of area, then a force of 3 nt is exerted on each cm^2. In other words, in this example the pressure would be 3 nt per cm^2.

If you know the total force F, and you also know the area on which this force is exerted (A), then how do you arrange these expressions to find force per unit area?

Please return to page 91 and pick a better answer.

ERIC

YOUR ANSWER --- D

How can you accept this?

If we believe that all molecular motion does not cease at 0^{o} K, then we must also believe that there is some internal kinetic energy in the body even at this temperature. Furthermore, no evidence is advanced to point to either the absence or presence of internal potential energy at absolute zero.

No, one of the answers is better than this. Please return to page 104 and try to find it.

ERIC

YOUR ANSWER --- B

It might have been obtained that way _if_ we had the proper instrument at our command. But since no mention is made of a pressure gauge, you cannot assume that the pressure was determined that way.

No. The pressure in nt/cm^2 is obtained from other data and pure logic. Think about it.

Please return to page 71. Pick the answer that makes physical sense.

YOUR ANSWER --- D

No, one of the answers is right.

We are dealing with 1,000 cm^3 of helium. The temperature is to be reduced over an interval of 250 C^o. The contraction then is:

$$1{,}000\ cm^3 \times \frac{250}{273}$$

The answer to this operation is then subtracted from the original volume to find the new volume. The final answer is one of those in the list.

Try again, please. Then return to page 67 and select the right answer.

ERIC

YOUR ANSWER --- D

No, one of the answers is right.

If you were asked what fraction part of 100 is represented by the number 50, you would answer this almost without thinking. You'd say that 50 is ½ of 100.

Well, to get this answer you set up a fraction like this:

$$\frac{50}{100} = \frac{1}{2}$$

so you can say that 50 is ½ of 100.

Now do the same thing with the problem at hand. Please return to page 61, work it out, then choose the right answer.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

ERIC

YOUR ANSWER --- B

This is incorrect.

Contraction per degree is found by subtracting one volume from another. For example, if you wanted to find the contraction between 0^{o} C and $-1.00\ ^{o}$ C, you would subtract 996.34 cm^3 from 1,000 cm^3. The same process is repeated to find the contraction from -1.00^{o} C to -2.00^{o} C, using the appropriate volumes.

In short, the contraction of a gas per degree Centigrade is simply the difference between the two volumes at the initial and final temperatures.

Your answer shows that you performed this subtraction improperly.

Please return to page 58 and choose another answer.

YOUR ANSWER --- B

Refer to Figure 3 on page 66 if you wish. You probably based this answer on the fact that the area of Piston 1 is 5 times as great as the area of Piston 2. Since we know that equal numbers of gas molecules strike equal surface areas in equal times at any given instant, the total force acting upward on Piston 1 must be 5 times as great as that on Piston 2. Up to this point, your thinking is correct. The force exerted by the gas upward on Piston 1 is definitely 5 times as great as the force exerted by the gas on Piston 2.

However, now compare the downward forces exerted by the 50-nt weight on the left Piston and the 10-nt weight on the right. Isn't the downward force on Piston 1 also 5 times as great as the downward force on Piston 2?

Please return to page 66. Choose another answer.

WORKSHEET

Please listen to Tape Segment 1 for Lesson 14 before starting to answer the questions below. PLEASE REFER TO THE ASSUMPTIONS ON PAGE 2 OF THE STUDY GUIDE WHILE LISTENING.

QUESTIONS

1. The fact that the molecules of an ideal gas move at random within the container (Assumption 1) is explained theoretically by

   A the straight line motion of the molecules between collisions.
   B the large number of molecular collisions per unit time.
   C the lack of elasticity in molecular collisions.
   D the flexibility of the walls of the container.
   E Newton's Law of Universal Gravitation.

2. Since molecules are assumed to be very small compared to the distances they travel between collisions (Assumption 3), they should be thought of as

   A spheres.
   B small cubes.
   C hollow objects.
   D massless objects.
   E points.

3. In the kinetic theory, which one of the following is ignored, or assumed not to exist?

   A Conservation of momentum.
   B Conservation of mechanical energy.
   C Elastic collisions.
   D Gravitational attraction between molecules.
   E Newton's first law.

4. In a perfectly cubical container, if there are x collisions per second of molecules against one particular wall, what will be the total number of collisions per second against all the walls of the container considered together?

   A 2x
   B 4x
   C 6x
   D 8x
   E 9x

Please return now to page 2 of the STUDY GUIDE.

WORKSHEET

Please listen to Tape Segment 2 for Lesson 14 before starting to answer the questions below. Refer to the Data Items as directed in the tape.

Data Item A: To go from lb/in^2 to nt/cm^2, we do this:

Step 1: Since 1 lb contains 4.45 nt, then

$$14.7 \frac{\cancel{lb}}{in^2} \times 4.45 \frac{nt}{\cancel{lb}} = 65.4 \frac{nt}{in^2}$$

Step 2: There are 2.54 cm in 1 inch, hence there are $(2.54 \times 2.54) cm^2$ in 1 in^2, so that

$$65.4 \frac{nt}{\cancel{in^2}} \times \frac{1}{(2.54 \times 2.54)} \frac{\cancel{in^2}}{cm^2} = 10.1 \frac{nt}{cm^2}$$

Data Item B: 1 millibar = 0.01 nt/cm^2

Multiplying both sides of the above by 1000:

1000 millibars = 10 nt/cm^2 and since 10 nt/cm^2 is approximately normal atmospheric pressure, then normal atmospheric pressure is roughly 1000 millibars.

To be correct to 4 significant digits, the U.S. Weather Bureau uses 1,013 millibars as Standard Atmospheric Pressure.

QUESTIONS

5. If you take normal atmospheric pressure as 10 nt/cm^2, the percent error compared to the actual value to 3 significant digits is

A 0.1%
B 1.0%
C 0.01%
D 10%
E 0.5%

6. A millibar is 1/1000 of a bar. How many newtons per square meter are there in 1 bar?

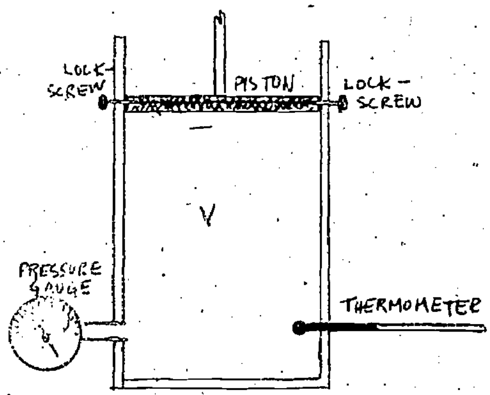
A 10^2
B 10^3
C 10^4
D 10^5
E 10^6

Please return now to page 105 of the STUDY GUIDE

WORKSHEET

Please listen to Tape Segment 3 for Lesson 14 before starting to answer the questions below. Refer to Data Item A as directed in the tape.

Data Item A:



Boyle's Law: $PV = k$ (T constant)

Charles' Law: $\frac{V}{T} = k$ (P constant)

General: $PV/T = P'V'/T'$

But if the volume is constant, then $V = V'$. Dividing through by the common V we obtain:

$$\frac{P}{T} = \frac{P'}{T'}$$

QUESTIONS

7. Despite the flexibility of rubber, a modern automobile tire is not considered to expand significantly when inflated as compared with its uninflated state. Thus, whether inflated fully, partially, or not at all

   A the pressure in a tire may be considered to remain constant.

   B the volume of air in a tire may be considered the same.

   C the temperature of the air cannot change.

   D both the pressure and temperature remain the same for all conditions.

   E none of the above is correct.

8. Suppose the temperature of the air in a tire rises from 27°C to 47°C due to road friction on a hot day. If the initial pressure was 45 lb/in^2, what would the final pressure be? (Don't forget to convert C-temperatures to Kelvin before you start.)

   A 48 lb/in^2 C 76.5 lb/in^2

   B 42.2 lb/in^2 D 25.8 lb/in^2

Please return now to page 69 of the STUDY GUIDE.

WORKSHEET

Please listen to Tape Segment 4 before starting to answer the questions below.

QUESTIONS

9. The gas laws as we have described and partially derived them apply only to

   A real gases.
   B monatomic gases like helium.
   C diatomic gases like oxygen.
   D all gases.
   E None of the above is correct.

10. The molecules of a real gas attract each other when they are brought sufficiently close; thus, real gases differ from ideal gases in this way, among others. If we greatly compress a real gas of given initial volume and temperature, will its temperature increase more, less, or the same as that of an ideal gas for the same conditions?

   A more
   B less
   C the same

When you have answered the questions, return to the tape and listen to the concluding segment for this Lesson. It contains important information regarding the terminal activities of this section of the course and must not be omitted.

At the conclusion of the tape, please return to page 19 of the STUDY GUIDE. Thank you.

AMP LESSON 14

HOMEWORK PROBLEMS

1. What is the Centigrade temperature when the absolute temperature is 20°K?

2. What is absolute zero on the Fahrenheit scale?

3. A sample of a gas occupies a volume of 586 cm^3 at 20°C. It is then heated to 40°C with no change of pressure. What is the volume of the gas at this new temperature?

4. The initial volume of a gas is 500 cm^3 at 76 cm of mercury. What will its pressure be after it is compressed to a volume of 300 cm^3 at constant temperature? (Express the new pressure in cm of mercury.)

5. A mass of gas at normal atmospheric pressure has a volume of 600 cm^3 at a temperature of 20°C. The container holding the gas is then placed in a tank of boiling water at normal pressure for 20 minutes. Assuming free expansion in the container, what volume will the gas occupy at the end of that time?

6. An oxygen tank of volume 2.00 ft^3 is filled to a pressure of 3000 lb/in^2. What was the original volume of the oxygen when it was at a pressure of 1 atmosphere. (Assume constant temperature.)

7. A mass of 1000 cm^3 of hydrogen at 27°C and a pressure of 80 cm of mercury is compressed until its volume is 250 cm^3 and its pressure is 400 cm of mercury. What is the centigrade temperature of the gas after compression?

ERIC