Physics 1021

Spring 2012, 18

ConcepTest 18a.1 molecular motion

If the position of a molecule is measured after increments of 10, 100, 1000 steps, what will the distribution of measured steps look like?

(1) No longer Gaussian

(2) Identical Gaussians

(3) Gaussians with half widths increasing with step size

(4) Gaussians with half widths decreasing with step size

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Just like in the random walk simulation, the width of the Gaussian should increase with the square root of time.

Thermal Physics
Describes and predicts the state of a system

What is a state?	Set of values that describe the current condition of a system, usually in equilibrium
Is this physics different than what we have learned?	No! At the microscopic level, the ideas of momentum and kinematics, forces and acceleration, energy conservation and Newton's Laws still apply.
Why do we learn it?	This is very practical. We can connect the ideal laws we have learned to useful, realistic systems, most of which are composed of large numbers of atoms and molecules
How do we make the connection to what we have learned so far?	We do this through statistics. For example when we measure the pressure of a gas, we are measuring average impulsive force of a large number of molecules colliding with the walls of our container.

Thermal Physics
Describes and predicts the state of a system

What is a state?	**Set of values that describe the current condition of a system, usually in equilibrium**
What are state variables?	Accurate, accepted descriptors. Temperature, pressure, Volume, concentration, density
What are not?	Things that change the state but do not describe it, or cannot be quantified as a content. Work, heat are important examples

Recovery

The fraction of and possible number of recoverable points is given in the table below:

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80 < s	10%	S = 85, 10% of 15 = 1.5 pts added to exam grade
60 < s < 80	15%	S = 70, 15% of 30 = 4.5 pts added to exam grade
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s < 40	25%	S = 20, 25% of 80 = 20 pts added to exam grade

Please note that participation in recovery is optional, and you will not be penalized for either incomplete or incorrect answers. It will not lower your exam grade

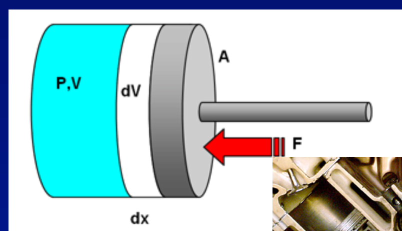
Today's agenda:

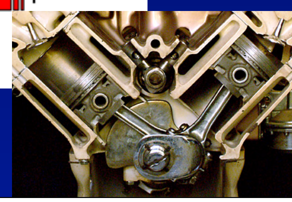
•Define and illustrate a number of important state variables.

•We will make the connection between microscopic mechanism and the macroscopic state description whenever possible.

•We will focus on the non-interacting gas (ideal gas), because it is simple and the ideas that develop from it are broadly applicable.

•We will calculate heat and work.
Our favorite example: the ideal gas in a piston.





$dW = Fdx$
$= PAdx$
$= PdV$

Molecular Speeds and Collisions

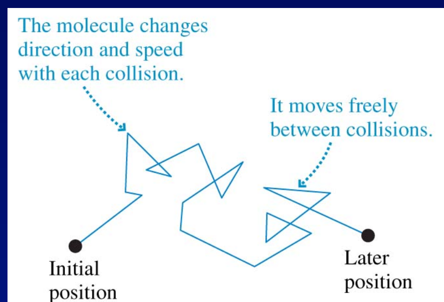
• A gas, liquid, or solid consists of a vast number of molecules, each moving randomly and undergoing millions of collisions every second.

•The micro/macro connection is built on the idea that the macroscopic properties of a system, such as temperature or pressure, are related to the *average* behavior of the atoms and molecules.

•The average can be found by measuring many molecules or by making many measurements of one molecule.

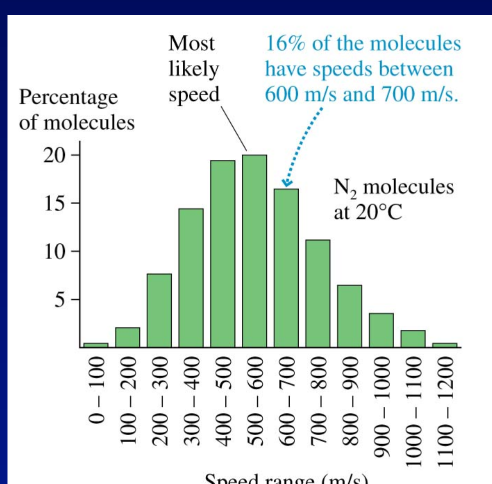
PHYS 11: Chap. 18, Pg 8

Molecular Speeds and Collisions



- In a gas or liquid, the molecules collide with one another and after each collisions get sent in random direction.
- The distribution of step sizes should then be a gaussian.
- This is the same for Brownian motion
- What is the average velocity?

Molecular Speeds and Collisions



- The average speed is calculated from the average of the velocity squared (rms):

$$s_{ave} = \sqrt{\langle v^2 \rangle}$$

- What is the average velocity?

ConcepTest 18a.2 velocity

The speed of every molecule in a gas is suddenly increased by a factor of 4. As a result, v_{rms} increases by a factor of

A. 2.
B. <4, but not necessarily 2.
C. 4.
D. >4 but not necessarily 16.
E. 16.

PHYS 11: Chap. 18, Pg 11

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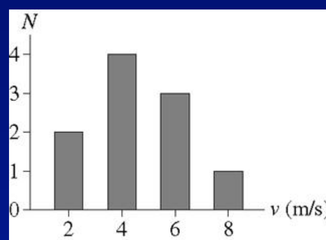
PHYS 11: Chap. 18, Pg 12

Ponderable: RMS and all that stuff

- The figure is a histogram showing the speeds of the molecules in a very small gas.

  What is (a) the average velocity, (b) the most probable speed, (c) the average speed, (c) the rms velocity?



Ponderable: Molecular Speeds and Collisions

The density of air at STP is about one thousandth the density of water. How does the average distance between air molecules compare to the average distance between water molecules? Explain.

Solids and liquids resist being compressed. They are not totally incompressible, but it takes large forces to compress them even slightly. If it is true that matter consists of atoms, what can you infer about the microscopic nature of solids and liquids from their incompressibility -- hint: think about the connection between total energy and PV?

Gases, in contrast with solids and liquids, are very compressible. What can you infer from this observation about the microscopic nature of gases?

Can you think of any everyday experiences or observations that would suggest that the molecules of a gas are in constant, random motion? (Note: The existence of "wind" is not such an observation. Wind implies that the gas as a whole can move, but it doesn't tell you anything about the motions of the individual molecules in the gas.)

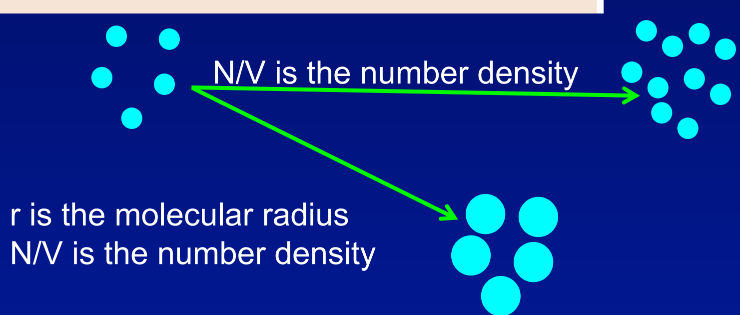
Position and velocity ↓ mean free path and temperature

New Topic

Mean Free Path

The **mean free path,** λ, is average distance a molecule travels before colliding with another molecule

$$\lambda = \frac{1}{4\sqrt{2}\pi(N/V)r^2} \qquad \text{(mean free path)}$$



Temperature in a Gas

- The thing we call *temperature* measures the average translational kinetic energy of molecules in a gas.
- A higher temperature corresponds to a larger value of ϵ_{avg} and thus to higher molecular speeds.
- *Absolute zero* is the temperature at which ϵ_{avg} and all molecular motion ceases.
- By definition, $\epsilon_{avg} = \frac{1}{2} m v_{rms}^2$, where v_{rms} is the root mean squared molecular speed. Using the ideal-gas law, we found $\epsilon_{avg} = 3/2\, k_B T$.
- By equating these expressions we find that the rms speed of molecules in a gas is

$$v_{rms} = \sqrt{\frac{3k_B T}{m}}$$

Pressure in a Gas

The pressure on the wall of a container due to all the molecular collisions is

$$p = \frac{F}{A} = \frac{1}{3}\frac{N}{V} m {v_{rms}}^2$$

This expresses the macroscopic pressure in terms of the microscopic physics. The pressure depends on the density of molecules in the container and on how fast, on average, the molecules are moving.

ConcepTest 18b.1 mean free path

The table shows the properties of four gases, each having the same number of molecules. Rank in order, from largest to smallest, the mean free paths λ_A to λ_D of molecules in these gases.

1. $\lambda_B > \lambda_A = \lambda_C > \lambda_D$
2. $\lambda_B > \lambda_A = \lambda_C = \lambda_D$
3. $\lambda_B = \lambda_C > \lambda_A = \lambda_D$
4. $\lambda_C > \lambda_D > \lambda_A = \lambda_B$
5. $\lambda_C > \lambda_A = \lambda_B = \lambda_D$

Gas	A	B	C	D
Volume	V	$2V$	V	V
Atomic mass	m	m	$2m$	m
Atomic radius	r	r	r	$2r$

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4. $\lambda_C > \lambda_D > \lambda_A = \lambda_B$
5. $\lambda_C > \lambda_A = \lambda_B = \lambda_D$

Bigger radius and smaller volume mean less room to move. Mass is irrelevant.

Gas	A	B	C	D
Volume	V	$2V$	V	V
Atomic mass	m	m	$2m$	m
Atomic radius	r	r	r	$2r$

Ponderable: Ideal Gas Law

- It is well known that you can trap liquid in a drinking straw by placing the tip of your finger over the top while the straw is in the liquid, then lifting it out. The liquid runs out when you release your finger.
- What is the net force on the cylinder of trapped liquid?
- Draw a free-body diagram for the trapped liquid. Label each vector.
- Is the gas pressure inside the straw, between the liquid and your finger, greater than, less than, or equal to atmospheric pressure? Explain.
- What has happened to the gas to change or not change its pressure?

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Ponderable: Chemistry or Physics?

- You are probably familiar with the ideal gas law as $PV = nRT$. In physics, it is often written as $PV = Nk_BT$
- Multiply Avogadro's number by Boltzman's constant and compare the product to the universal gas constant.
- What can you say about the two versions of the ideal gas law, based on this comparison?
- In what types of problems would one be more appropriate to use than the other?

Ponderable: Molecular Speeds and Collisions

Helium has atomic mass number A = 4. Neon has A = 20 and argon has A = 40. Rank in order, from largest to smallest, the mean free paths of He, Ne, and Ar at STP. Explain.