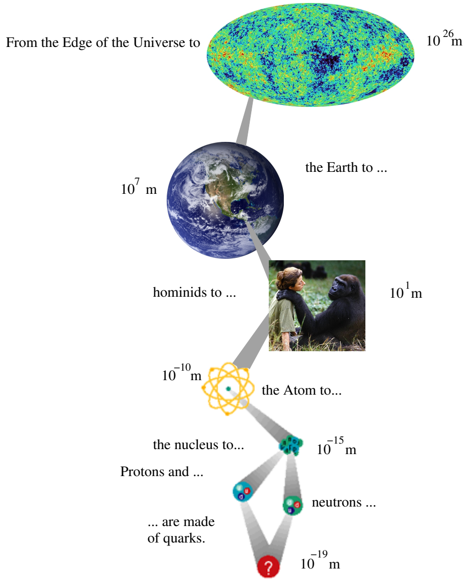
Personal Information

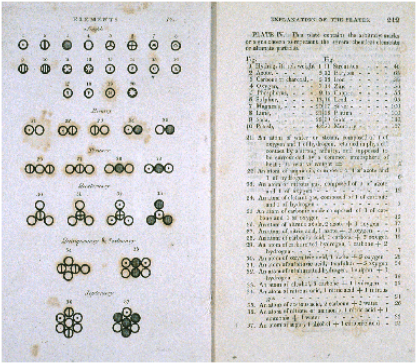
- Name:
- Did you take Phys 131 and who was your instructor?
- How many semesters of physics before this course (high school or college)?
- How many semesters of calculus before this course (high school or college)?
- Preferred personal pronouns?



From the Edge of the Universe to
10^{26} m
the Earth to ...
10^{7} m
hominids to ...
10^{1} m
10^{-10} m
the Atom to...
the nucleus to...
10^{-15} m
Protons and ...
neutrons ...
... are made of quarks.
10^{-19} m

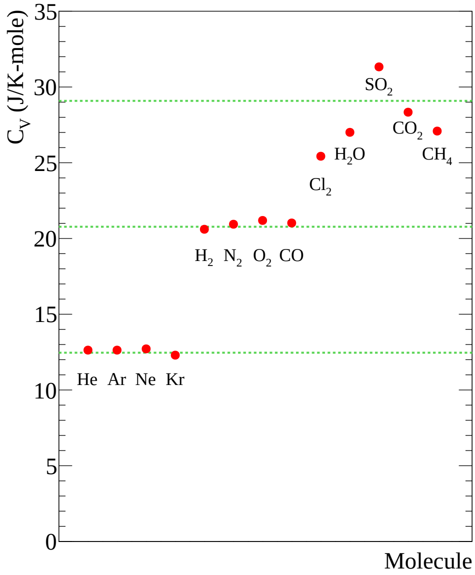
Dalton's Atomic Theory (1808)

1. All matter consists of tiny particles.
2. Atoms are indestructible and unchangeable.
3. Elements are characterized by the mass of their atoms.
4. When elements react, their atoms combine in simple, whole-number ratios.



from *A New System of Chemical Philosophy (1808)* by John Dalton

Specific Heats of Gases



1. Boltzmann's kinetic theory laid the groundwork the atomic theory.
2. Connects bulk properties to microscopic motion of atoms.
3. Calculated gas specific heats from fundamental concepts.

Specific Heats of Ideal Gases

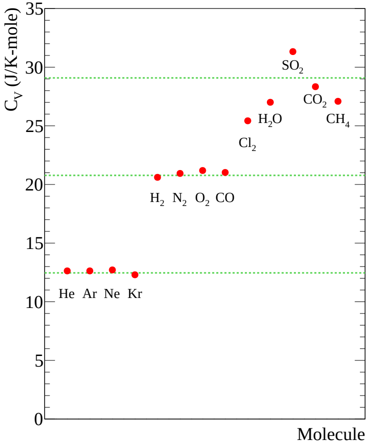
Assume that a pure, ideal gas is made of tiny particles that bounce into each other and the walls of their cubic container of side ℓ. Show the average pressure P exerted by this gas is

$$P = \frac{1}{3}\frac{N}{V}m\overline{v_{total}^2}$$

Use the ideal gas law ($PV = Nk_B T = nRT$)and the conservation of energy ($\Delta E_{int} = C_V \Delta T$) to calculate the specific heat of an ideal gas and show the following.

$$C_V = \frac{3}{2}N_A k_B$$

Is this right?



N - number of particles

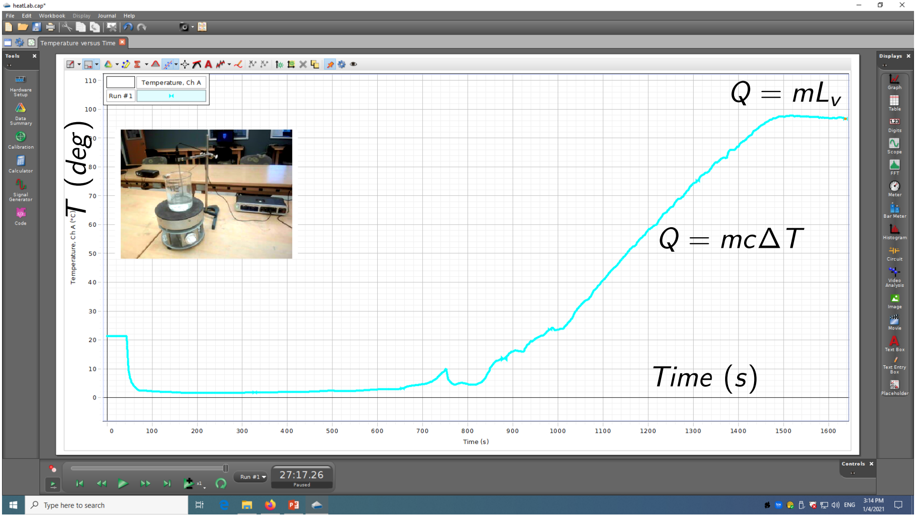
k_B - Boltzmann constant

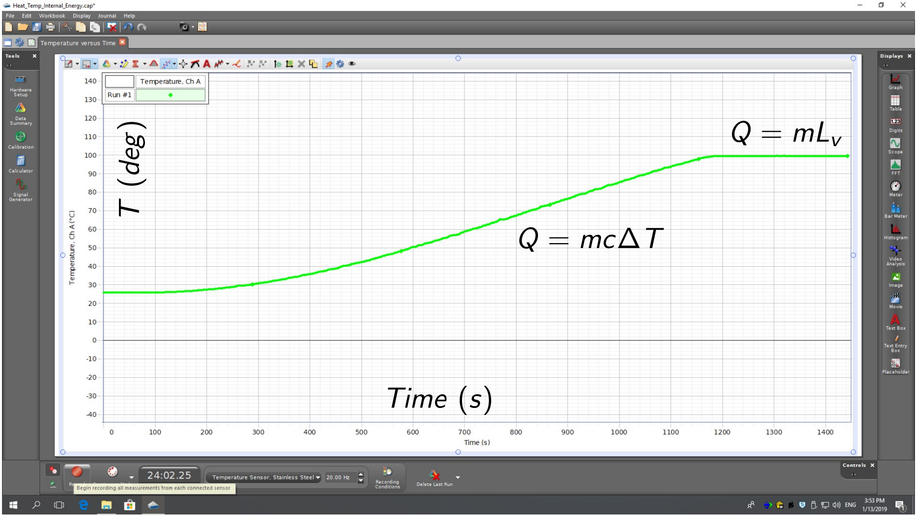
N_A - Avogadro's number

$V = \ell^3$

m - atomic mass

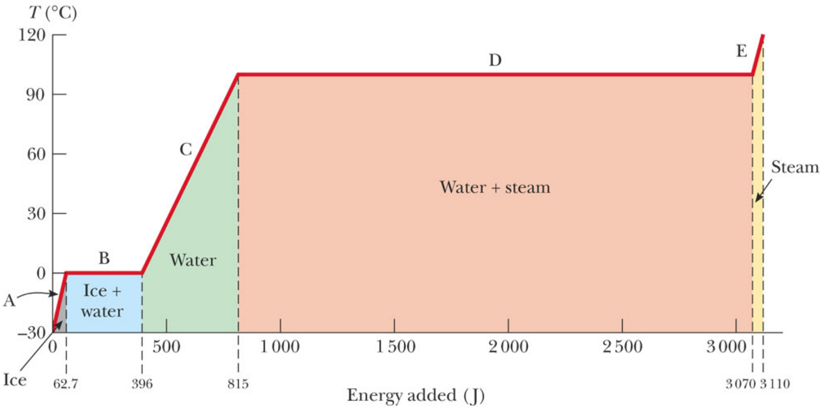
v_{total} - atom's speed


heatLab.cap*
File Edit Workbook Display Journal Help
Temperature versus Time
Temperature, Ch A
Run #1
$Q = mL_v$
$Q = mc\Delta T$
T (deg)
Temperature, Ch A (°C)
Time (s)
27:17.26
Paused



Heat_Temp_Internal_Energy.cap*
Temperature versus Time
Temperature, Ch A
Run #1
T (deg)
$Q = mL_v$
$Q = mc\Delta T$
Time (s)
Temperature, Ch A (°C)
24:02.25
Temperature Sensor, Stainless Steel
20.00 Hz
Begin recording all measurements from each connected sensor

Heat (Q) is thermal energy transferred from one place or body to another due to a difference in temperature. Thermal energy is the mechanical energy (kinetic and potential) associated with atomic motion in an object.



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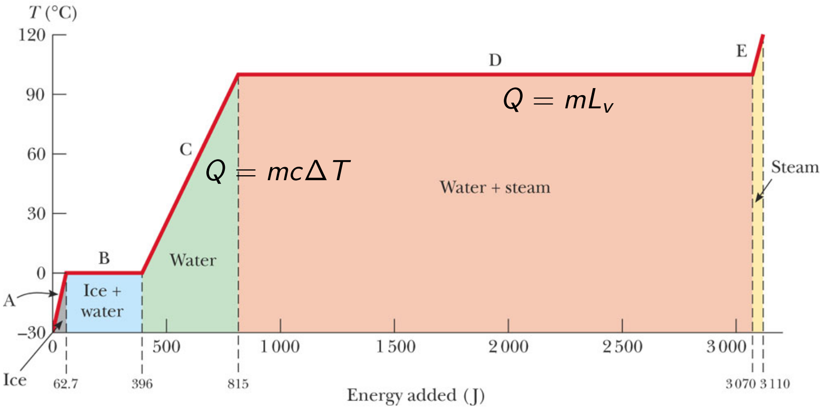
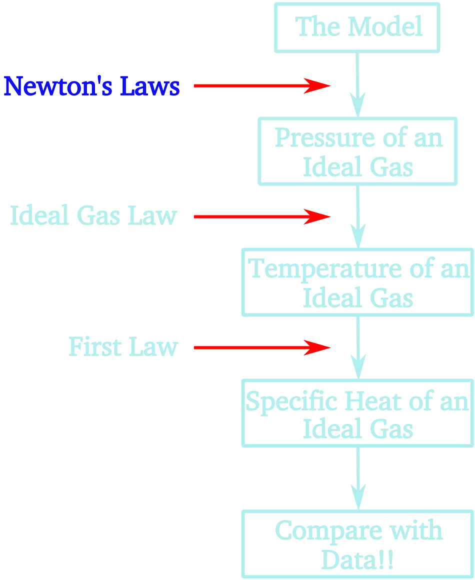
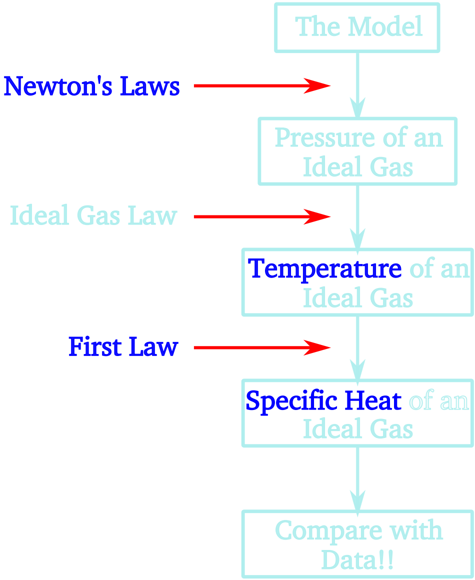


Two ice cubes each with mass $m_I = 0.050\ kg$ are taken from a freezer at $T_0 = 0°\mathrm{C}$ and dropped into a container holding $m_w = 1.0\ kg$ of water at $T_1 = 25°\mathrm{C}$. What will be the final temperature of the liquid? Assume the container absorbs no heat.

$c_{ice} = 2090\ J/kg - K$
$c_w = 4186\ J/kg - K$
$L_f = 3.33 \times 10^5\ J/kg$


The Model
Newton's Laws
Pressure of an Ideal Gas
Ideal Gas Law
Temperature of an Ideal Gas
First Law
Specific Heat of an Ideal Gas
Compare with Data!!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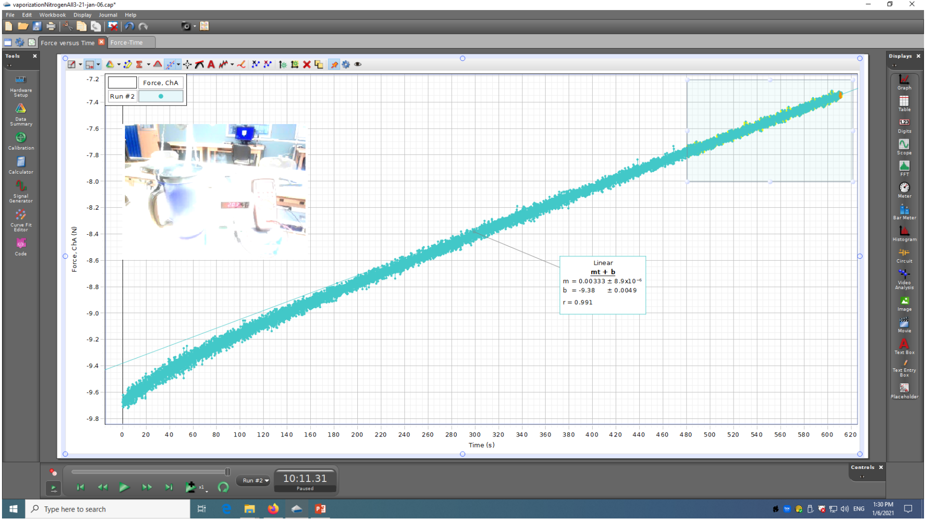
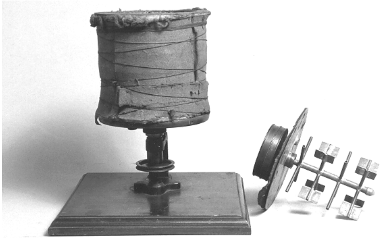
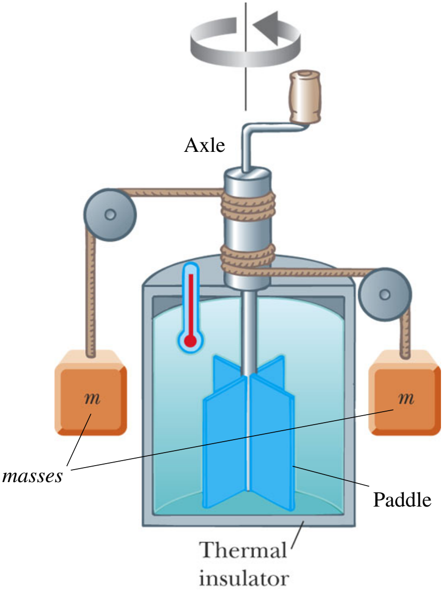


vaporizationNitrogenAll3-21-jan-06.cap*
File Edit Workbook Display Journal Help
Force versus Time
Force-Time
Force, ChA
Run #2
Force, ChA (N)
Time (s)
Linear
mt + b
m = 0.00333 ± 8.9x10⁻⁶
b = -9.38 ± 0.0049
r = 0.991
Run #2
10:11.31
Paused
Type here to search

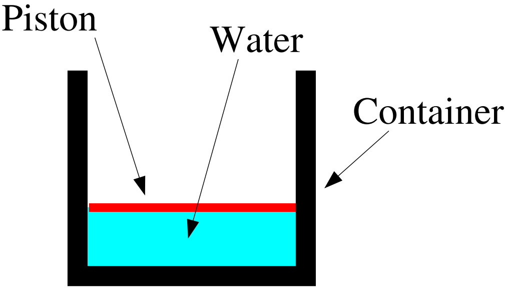


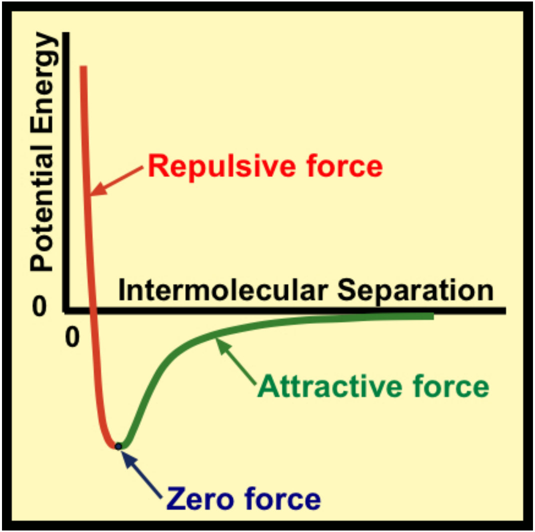
Joule's original apparatus



Let 1.00 kg of liquid water at 100° C be converted to steam at 100° C. The water is contained in a cylinder with a movable piston of negligible mass that sits right on top of the water at the start. The volume changes from an initial value of 1.00×10^{-3} m^3 as a liquid to 1.671 m^3 as steam. The latent heat of vaporization of water is $L_V = 2.26 \times 10^6$ J/kg and atmospheric pressure is $P_{atm} = 1.01 \times 10^5$ Pa.

1. How much work is done by this process?
2. How much heat must be added?
3. What is the change in the water's internal energy?





The energy diagram for two molecules.

A weather balloon is loosely inflated to a volume $V_0 = 2.2\ m^3$ with helium at a pressure of $P_0 = 1.0 \times 10^5\ Pa$ and a temperature $T_0 = 20°\mathrm{C}$. At an elevation of 20,000 ft the atmospheric pressure is down to $P_1 = 0.5 \times 10^5\ Pa$ and the temperature is $T_1 = -48°\mathrm{C}$. The bag can expand freely. What is the new volume of the bag? What is the gas mass?

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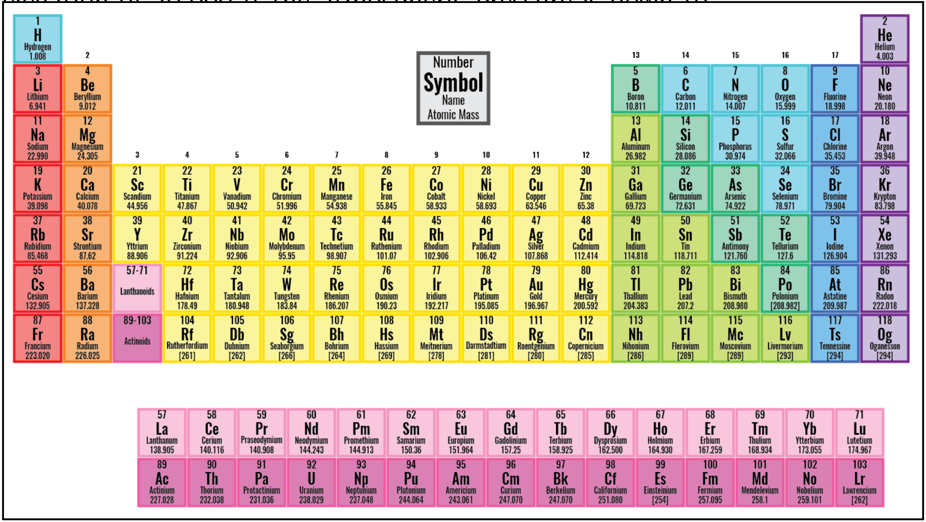

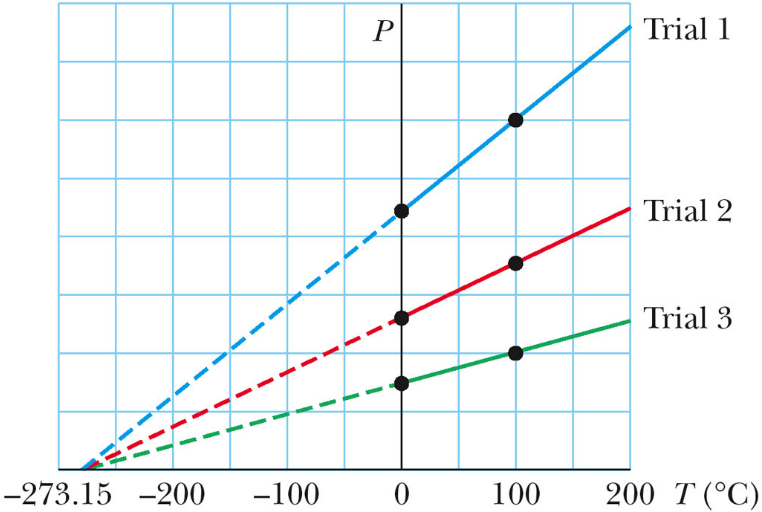
P
Trial 1
Trial 2
Trial 3
–273.15
–200
–100
0
100
200
T (°C)

A steel tank contains $m_g = 0.30\ kg$ of ammonia gas $(\mathrm{NH_3})$ at an absolute pressure $P_0 = 1.35 \times 10^5\ N/m^2$ and a temperature $T_0 = 77^\circ\ C$. What is the volume of the tank? At a later time the tank is checked. The temperature has fallen to $T_1 = 22^\circ\ C$ and the pressure has fallen to $P_1 = 8.7 \times 10^5\ N/m^2$. How many kilograms of gas leaked out of the tank?

Assume that a pure, ideal gas is made of tiny particles that bounce into each other and the walls of their cubic container of side ℓ. Show the average pressure P exerted by this gas is

$$P = \frac{1}{3}\frac{N}{V}m\overline{v_{total}^2}$$

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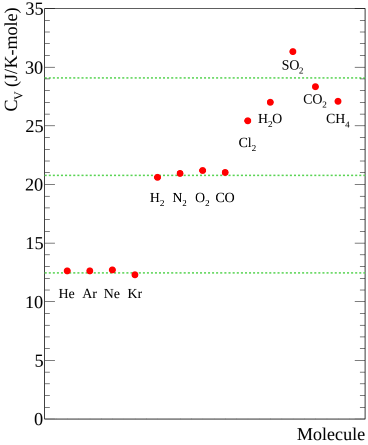
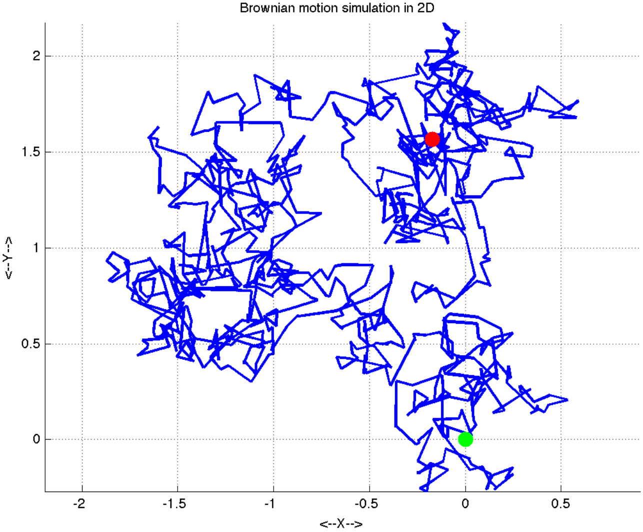


N - number of particles
k_B - Boltzmann constant
N_A - Avogadro's number

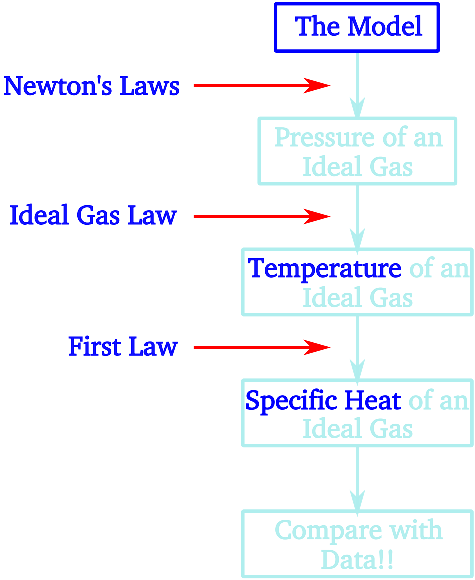
$V = \ell^3$
m - atomic mass
v_{total} - atom's speed

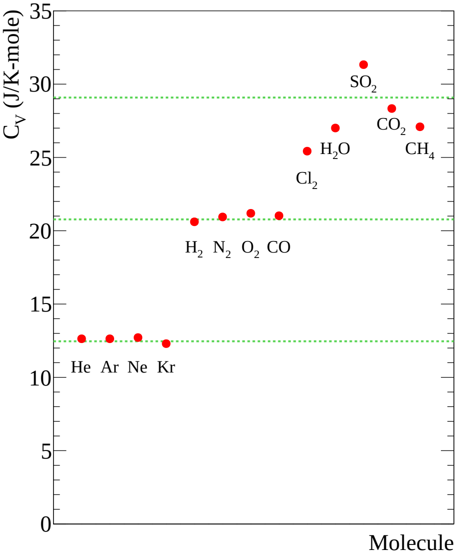
1. The gas consists of a large number of small, mobile particles and their average separation is large.
2. The particles obey Newton's Laws and the conservation laws, but their motion can be described statistically.
3. The particles' collisions are elastic on average.
4. The inter-particle forces are small until they collide.
5. The gas is pure.
6. The gas is in thermal equilibrium with the container walls.



Click here

The Plan


The Model
Newton's Laws
Pressure of an Ideal Gas
Ideal Gas Law
Temperature of an Ideal Gas
First Law
Specific Heat of an Ideal Gas
Compare with Data!!

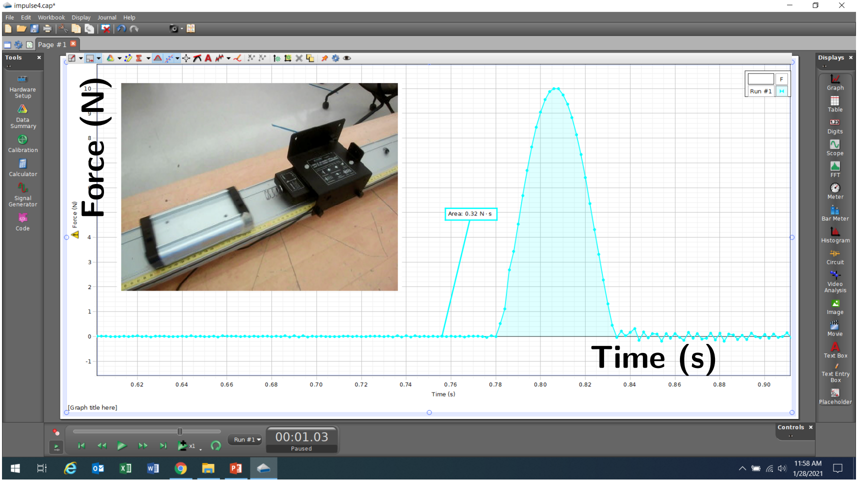


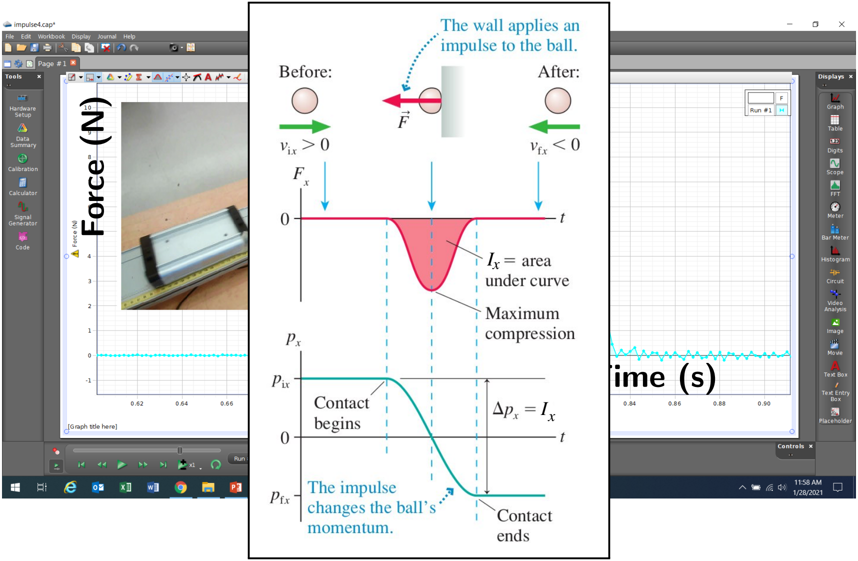
$\frac{7}{2}R = \frac{7}{2}N_A k_B$

$\frac{5}{2}R = \frac{5}{2}N_A k_B$

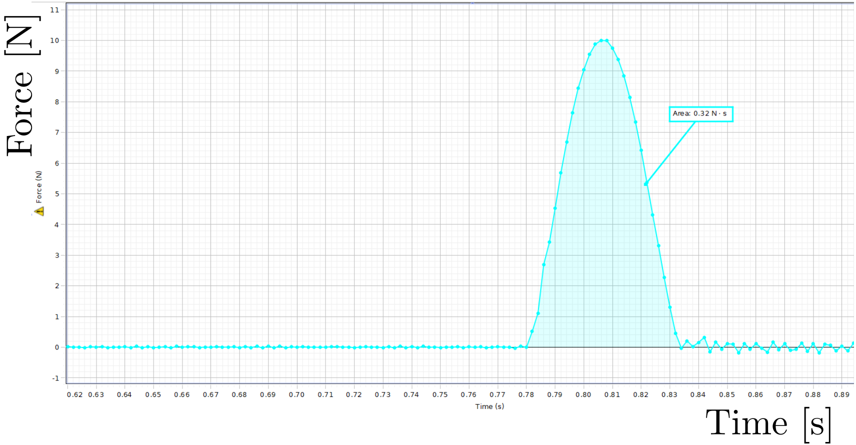
$\frac{3}{2}R = \frac{3}{2}N_A k_B$

The Pressure of an Ideal Gas - Impulse and Momentum Change

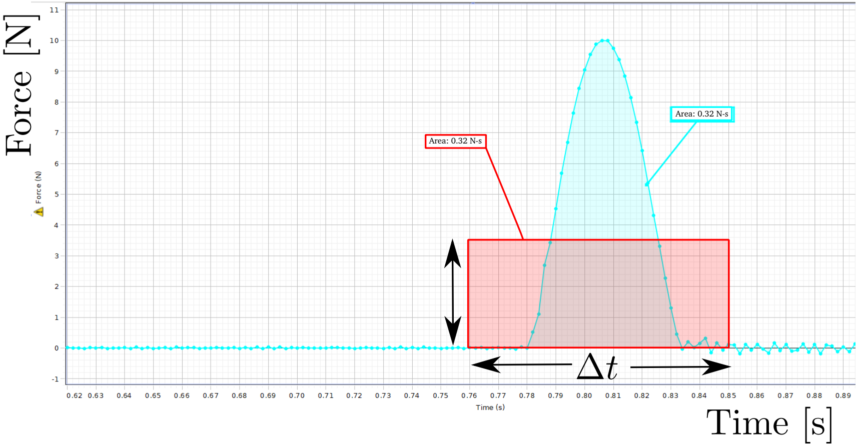


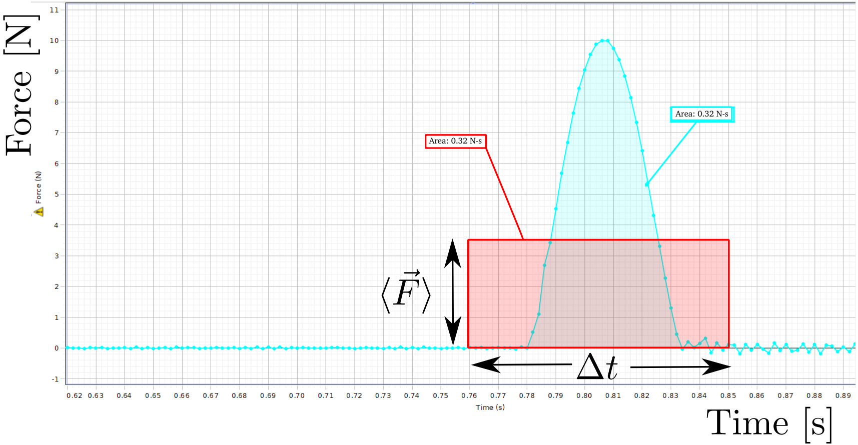


The wall applies an impulse to the ball.
Before:
After:
$\vec{F}$
$v_{ix} > 0$
$v_{fx} < 0$
F_x
0
t
I_x = area under curve
Maximum compression
p_x
p_{ix}
Contact begins
$\Delta p_x = I_x$
0
t
p_{fx}
The impulse changes the ball's momentum.
Contact ends

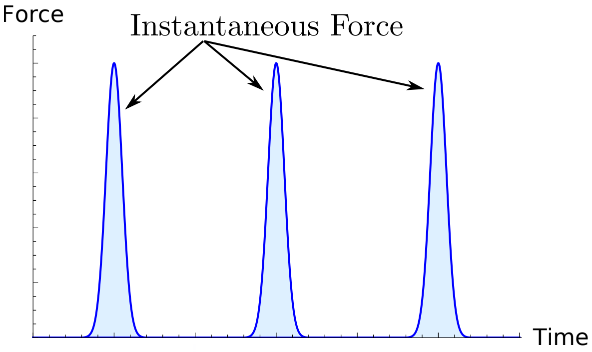


Force [N]
Force (N)
Area: 0.32 N · s
0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72 0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89
Time (s)
Time [s]

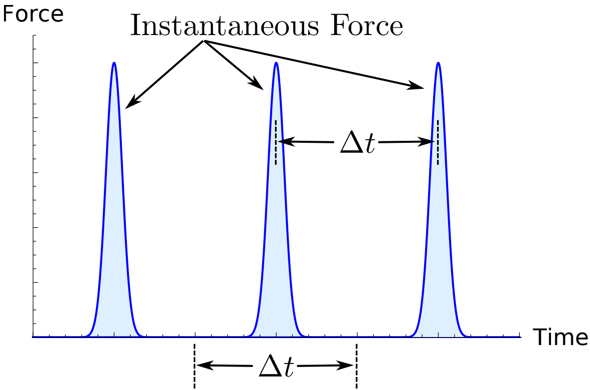

Force [N]
Force (N)
11
10
9
8
7
6
5
4
3
2
1
0
-1
Area: 0.32 N-s
Area: 0.32 N-s
Δt
0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72 0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89
Time (s)
Time [s]



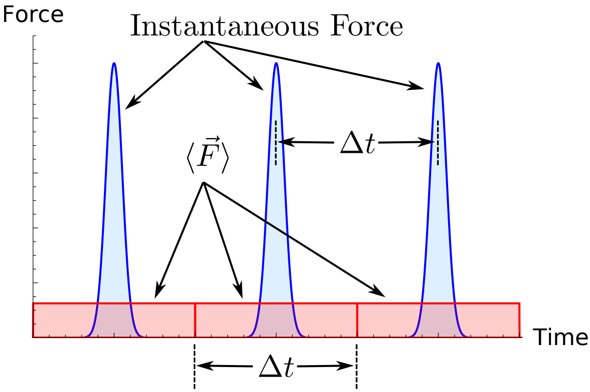
Force [N]
Force (N)
Time [s]
Time (s)
Area: 0.32 N-s
Area: 0.32 N-s
$\langle\vec{F}\rangle$
Δt
11
10
9
8
7
6
5
4
3
2
1
0
-1
0.62 0.63 0.64 0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72 0.73 0.74 0.75 0.76 0.77 0.78 0.79 0.80 0.81 0.82 0.83 0.84 0.85 0.86 0.87 0.88 0.89



1. Consider a tiny patch of the container.
2. It's repeatedly hit by gas particles (blue).



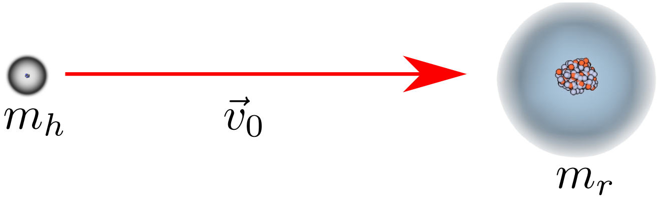
1. Consider a tiny patch of the container.
2. It's repeatedly hit by gas particles (blue).
3. The average time separation is Δt.

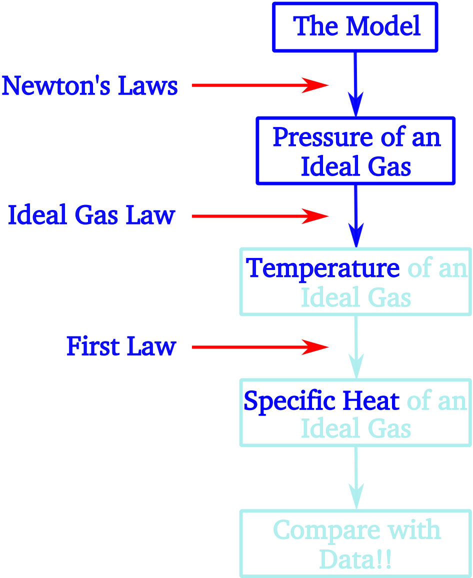


1. Consider a tiny patch of the container.
2. It's repeatedly hit by gas particles (blue).
3. The average time separation is Δt.
4. Average force is red.
5. Blue area = Red area

Momentum Conservation and Hitting Walls 34

An atom of mass m_h collides elastically head-on with a heavier, stationary, target atom of mass m_r. Both particles are free to move in space. The initial velocity of the projectile is $\vec{v}_0$ as shown below. What is the final velocity $\vec{v}_1$ of the projectile in terms of the masses, $\vec{v}_0$, and any other constants? What happens to the final velocity $\vec{v}_1$ as the target mass m_r becomes very large? Ignore the effects of potential energy.




The Model
Newton's Laws
Pressure of an Ideal Gas
Ideal Gas Law
Temperature of an Ideal Gas
First Law
Specific Heat of an Ideal Gas
Compare with Data!!

Is Potential Energy Important?

A helium atom is moving straight up from the floor of the lab that is at room temperature $T = 300\ K$. Miraculously, the atom never strikes another atom or molecule until it reaches the ceiling at a height $h = 4.0\ m$ above the floor. What is the helium atom's rms speed when it hits the ceiling? How much has its speed changed from the initial speed?

Assume that a pure, ideal gas is made of tiny particles that bounce into each other and the walls of their cubic container of side ℓ. Show the average pressure P exerted by this gas is

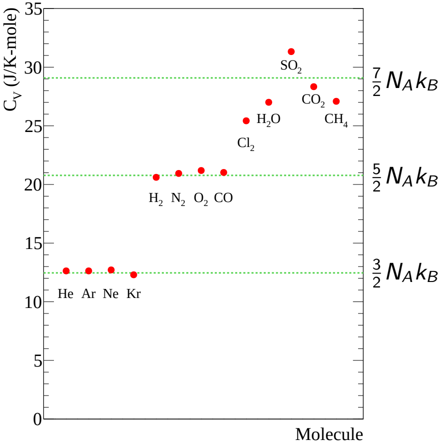
$$P = \frac{1}{3}\frac{N}{V}m\overline{v_{total}^2}$$

Use the ideal gas law ($PV = Nk_BT = nRT$)and the conservation of energy ($\Delta E_{int} = C_V \Delta T$) to calculate the specific heat of an ideal gas and show the following.

$$C_V = \frac{3}{2}N_A k_B = \frac{3}{2}R$$

Is this right?

N - number of particles $V = \ell^3$
k_B - Boltzmann constant m - atomic mass
N_A - Avogadro's number v_{total} - atom's spe



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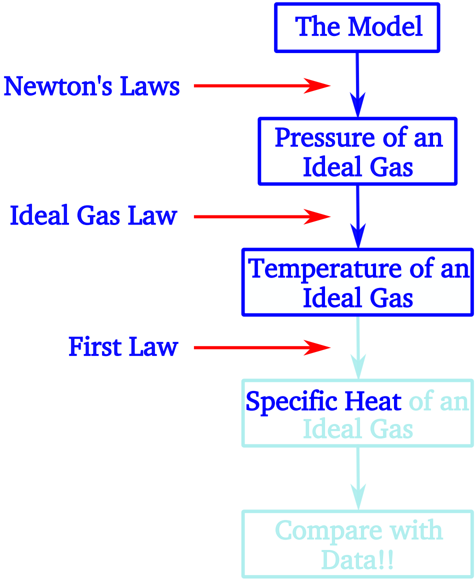
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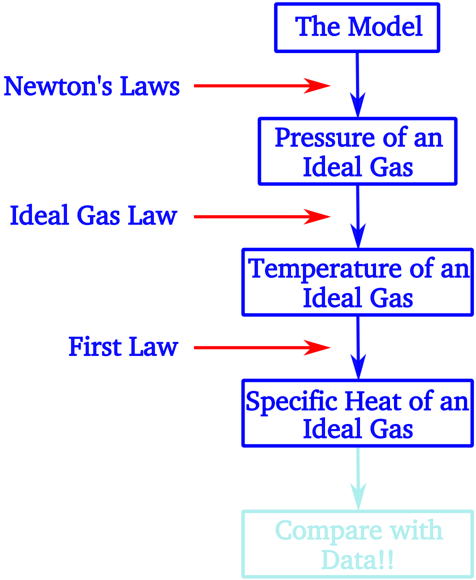
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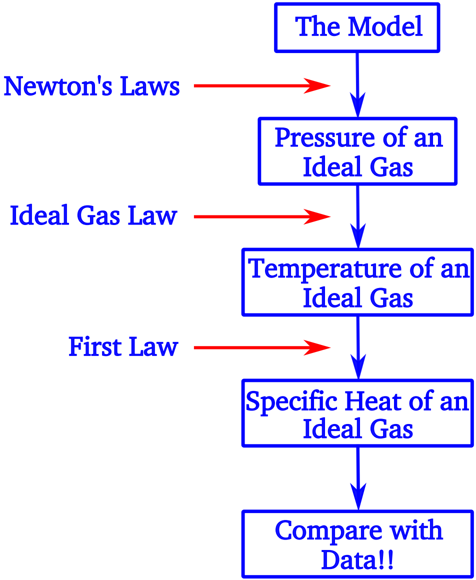
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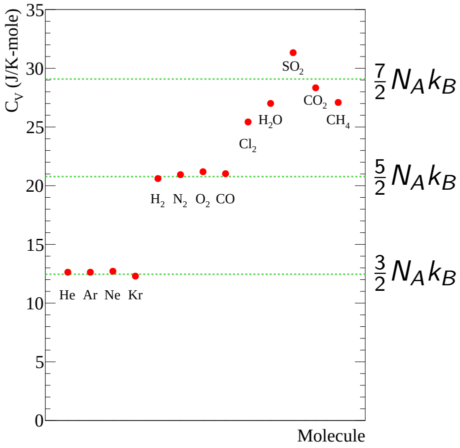
Compare with Data!!

$$P = \frac{1}{3}\frac{N}{V}m\overline{v^2_{total}} = \frac{2}{3}\frac{N}{V}\langle E_{kin}\rangle$$

$$\langle E_{kin}\rangle = \frac{3}{2}Nk_B T$$

$$C_V = \frac{3}{2}N_A k_B = \frac{3}{2}R$$



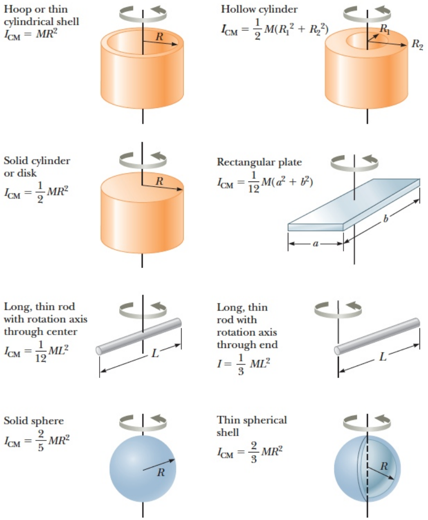
Rotational Kinetic Energy

Classically

$$E_{rot} = \frac{L^2}{2I}$$

where

$$I = \sum m r_i^2 = \int r^2 dm$$



Classically

$$E_{rot} = \frac{L^2}{2I}$$

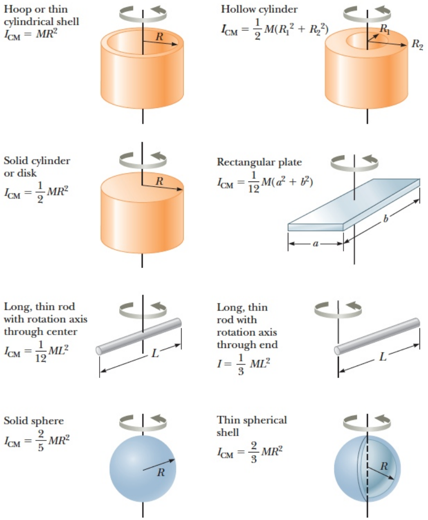
where

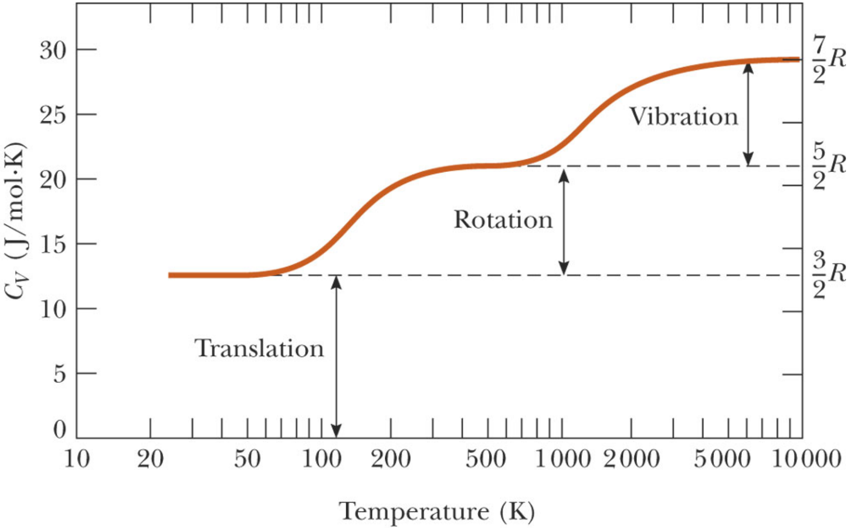
$$I = \sum m r_i^2 = \int r^2 dm$$

Quantum mechanically

$$E_{rot}^{qm} = l(l+1)\frac{\hbar^2}{2I}$$

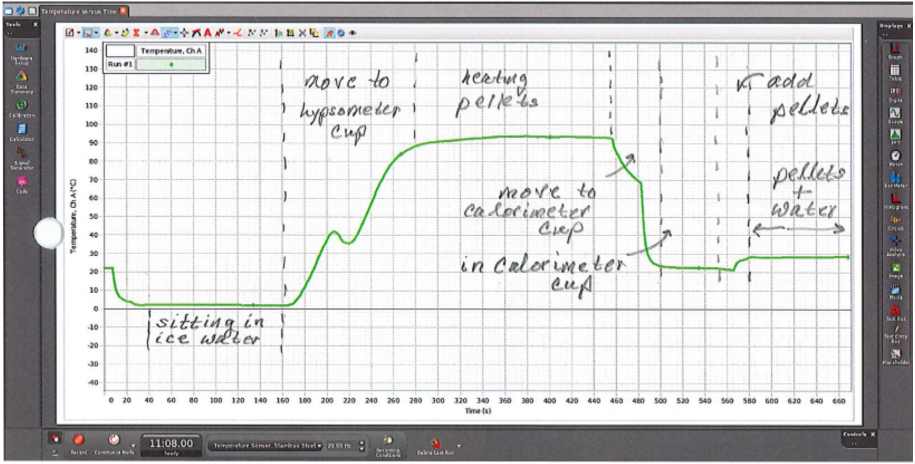
where l is the angular momentum quantum number.





30
25
20
15
10
5
0
C_V (J/mol·K)
10
20
50
100
200
500
1000
2000
5000
10000
Temperature (K)
Translation
Rotation
Vibration
$\frac{7}{2}R$
$\frac{5}{2}R$
$\frac{3}{2}R$

How much heat does it take to increase the temperature of $n = 4.0$ *moles* of $\mathrm{H_2}$ gas by $\Delta\mathrm{T} = 25\ \mathrm{K}$ at room temperature $\mathrm{T} = 25^\circ\mathrm{C}$ if the gas is held at constant volume? Would the answer change if the gas were $\mathrm{N_2}$? What about He?



Temperature, Ch A
Run #1
Temperature, Ch A (°C)
Time (s)
move to hypsometer cup
heating pellets
add pellets
pellets + water
move to calorimeter cup
in calorimeter cup
sitting in ice water
11:08.00

Installing Capstone

1. Go to the website

   `https://www.pasco.com/downloads/capstone`

   and select the free trial for your platform (Windows or Mac). The installer will be downloaded to your machine.
2. Launch the installer you just downloaded.
3. Accept defaults.
4. On first launch, enter the license key listed below.

   19F5C-S10o2-4o0m0-ppip3-40qr8-ece1h
5. The capstone files for each lab will be linked to the lab schedule on the course website at the following location.

   `https://facultystaff.richmond.edu/~ggilfoyl/genphys.html`

TABLE 17.3 Melting/boiling temperatures and heats of transformation

Substance	T_m (°C)	L_f (J/kg)	T_b (°C)	L_v (J/kg)
Nitrogen (N_2)	−210	0.26×10^5	−196	1.99×10^5
Ethyl alcohol	−114	1.09×10^5	78	8.79×10^5
Mercury	−39	0.11×10^5	357	2.96×10^5
Water	0	3.33×10^5	100	22.6×10^5
Lead	328	0.25×10^5	1750	8.58×10^5

TABLE 17.2 Specific heats and molar specific heats of solids and liquids

Substance	c (J/kg K)	C (J/mol K)
Solids		
Aluminum	900	24.3
Copper	385	24.4
Iron	449	25.1
Gold	129	25.4
Lead	128	26.5
Ice	2090	37.6
Liquids		
Ethyl alcohol	2400	110.4
Mercury	140	28.1
Water	4190	75.4