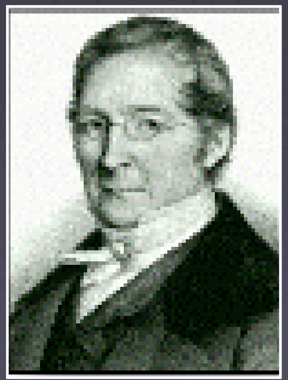
Boyle's Charles' & Gay-Lussac's Gas Laws



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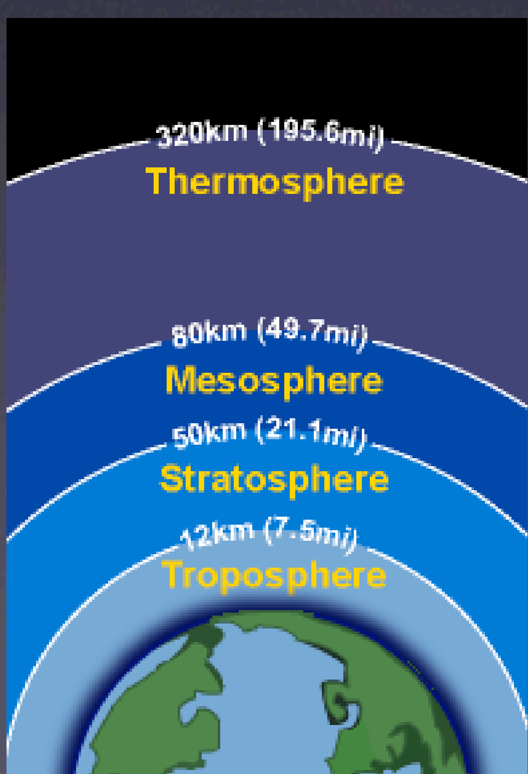
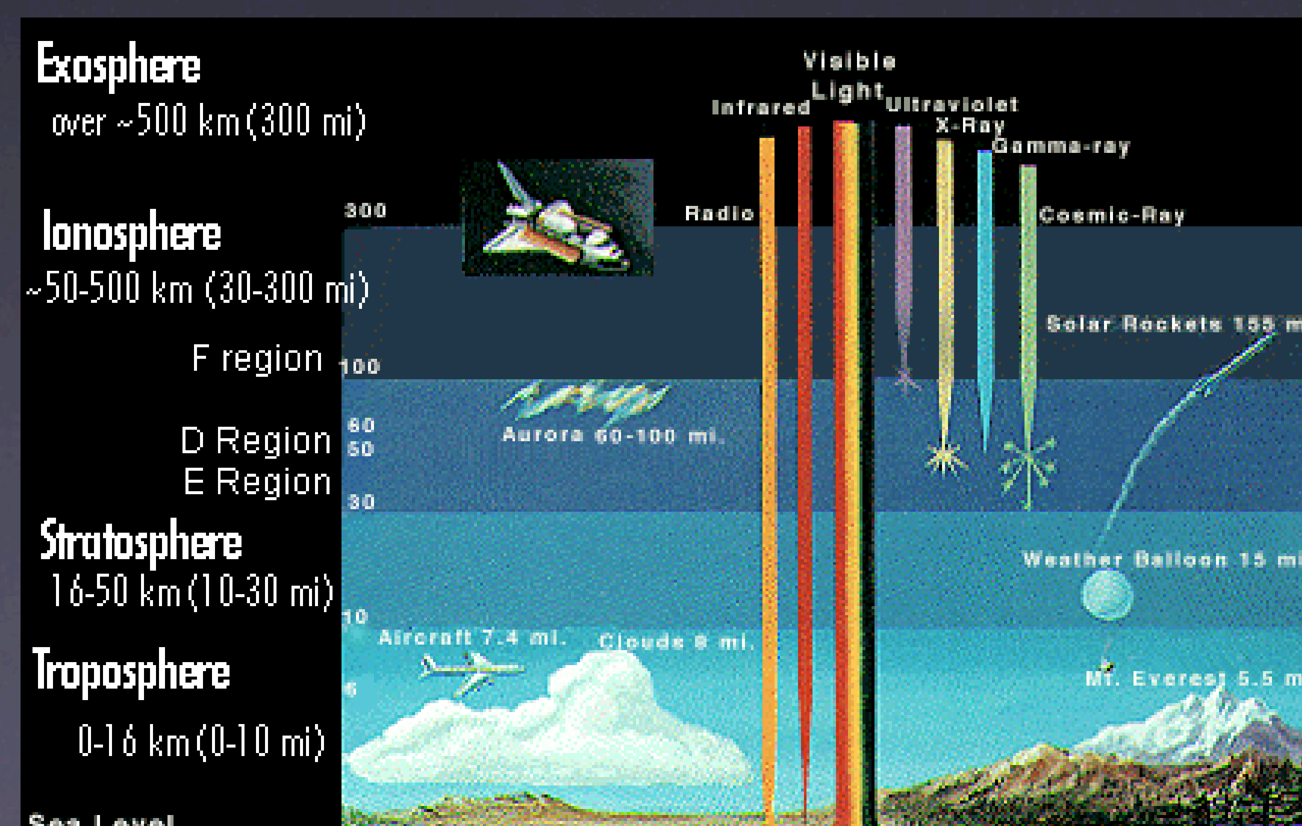
Our Atmosphere

We live our lives in a gaseous atmosphere consisting of 78% nitrogen, 21% oxygen and 1% H_2O and CO_2. While it rises above us to an altitude of around 300 km. (200 miles), over 50% of the air is found within 5 miles of the surface.

Without an atmosphere, no life would exist on earth.



At the Earth's surface the atmospheric pressure is 14.7 lbs/sq. inch abbr: 14.7 psi (1.0 atm.)



Measuring Gases

T

Temperature is a measurement of the average kinetic energy of the particles in matter. It is measured in °Celsius or Kelvin.

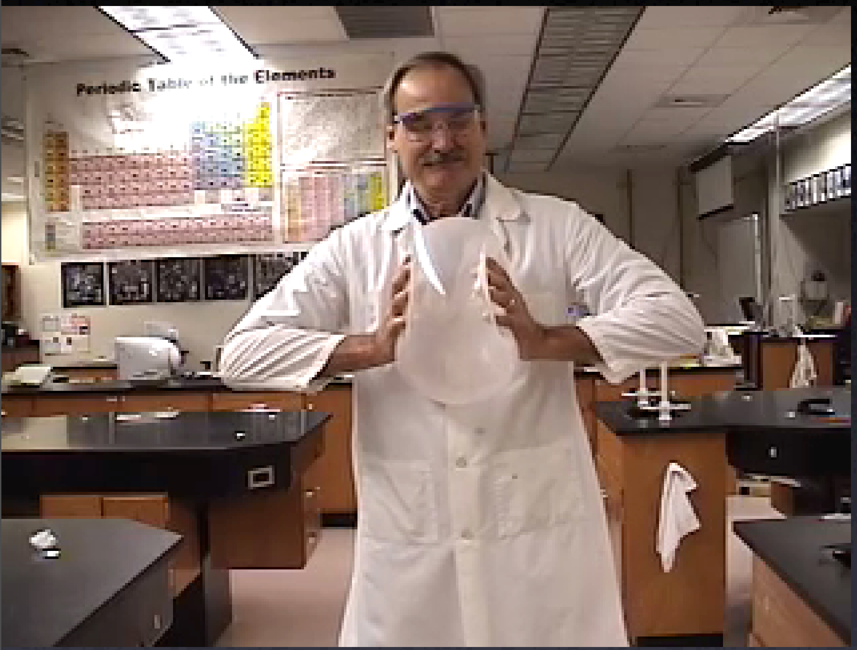
V

Volume is the amount of space a substance takes up. It is measured in mL or L.

P

Pressure is the amount of force exerted over a certain amount of area ($P = F/a$). Atmospheric pressure is measured in atmospheres, abbreviate atm.

Pressure, Force & Area

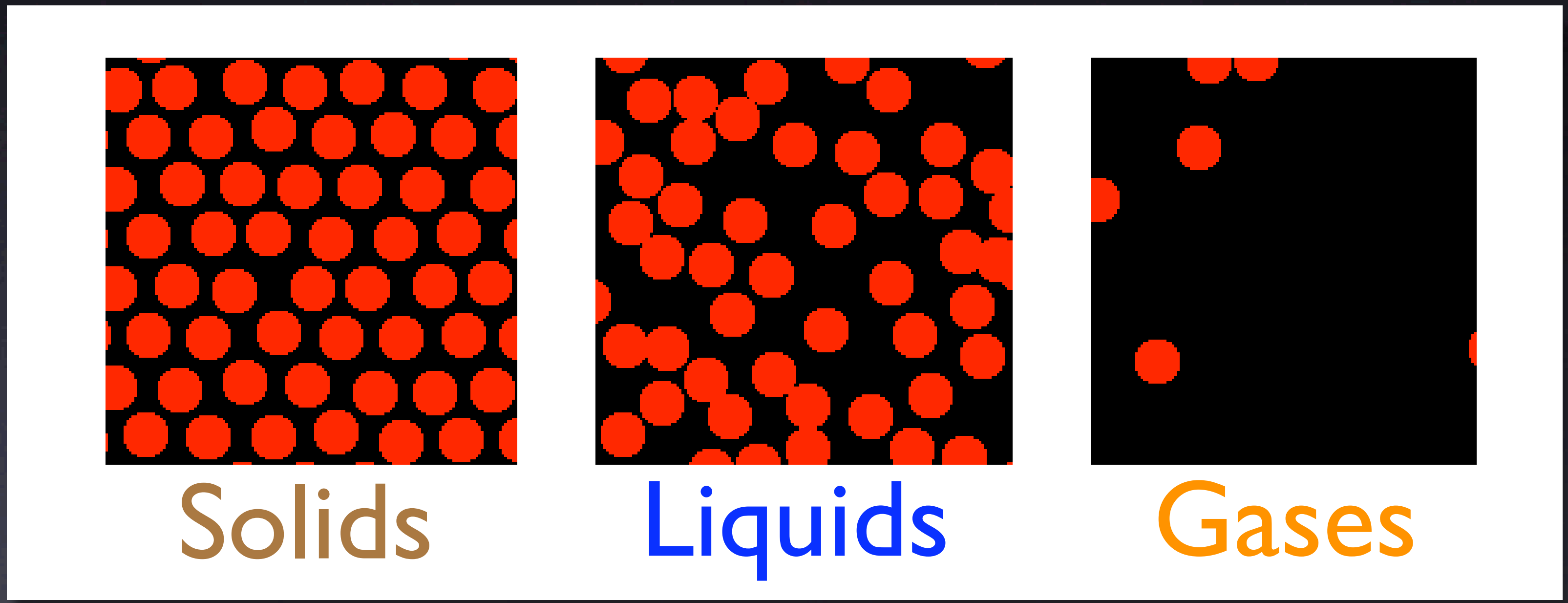


$$P = \frac{F}{A}$$

Pressure and Force
are directly proportional.
If force doubles,
pressure doubles.

Pressure and Area
are inversely proportional.
If area doubles,
pressure is cut in half.

Kinetic Theory:
It's All in the Motion!



Solids - particles vibrate in place.

Liquids - particles are close together and are free to move.

Gases - particles are moving freely & very fast.

Boyle’s Law

Robert Boyle (1627-1691)

Born in England in 1627, the 7th of 14 children, Robert learned Greek, Latin and French by the time he was 6.

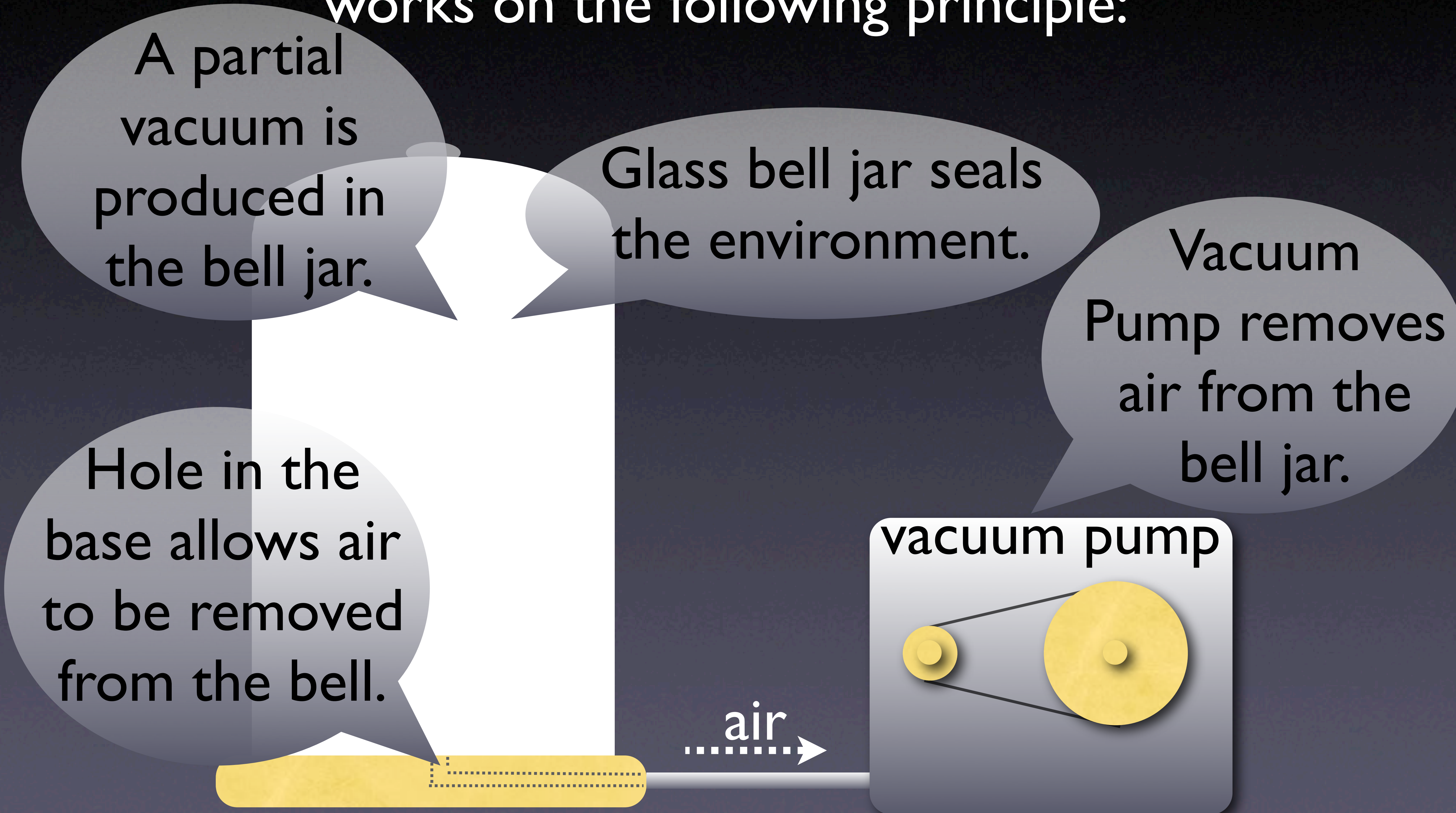
At the age of 8 he attended Eton College and, after graduating at age 12, traveled throughout Europe with a French tutor.

In his 20's, Robert began investigating the properties of gases. He invented the vacuum pump and was first to discover that sound cannot travel through a vacuum. Through experimentation on gases he established Boyle's Law which states that a gases' pressure and volume are inversely proportional.

The formula for Boyle's Law: $P_1 \times V_1 = P_2 \times V_2$

Vacuum Bell Jar

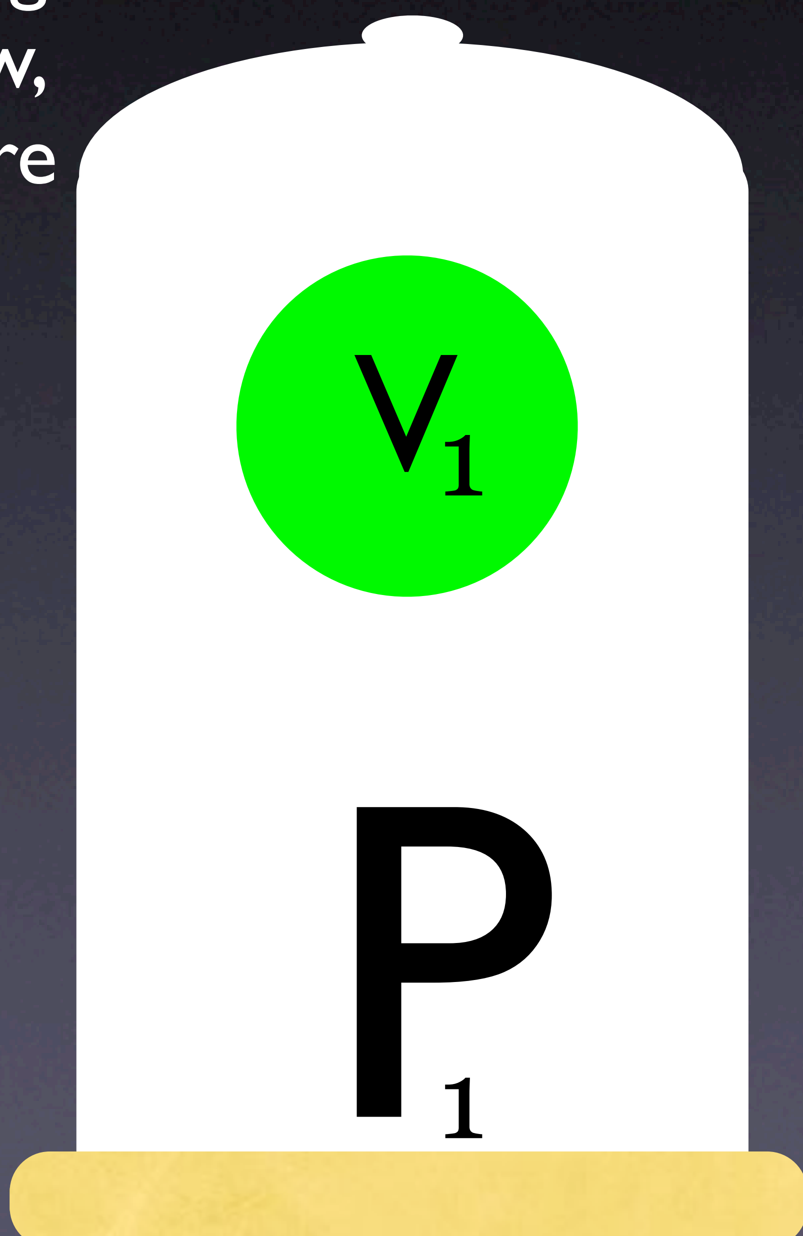
The vacuum bell jar, invented by Boyle in 1652, works on the following principle:



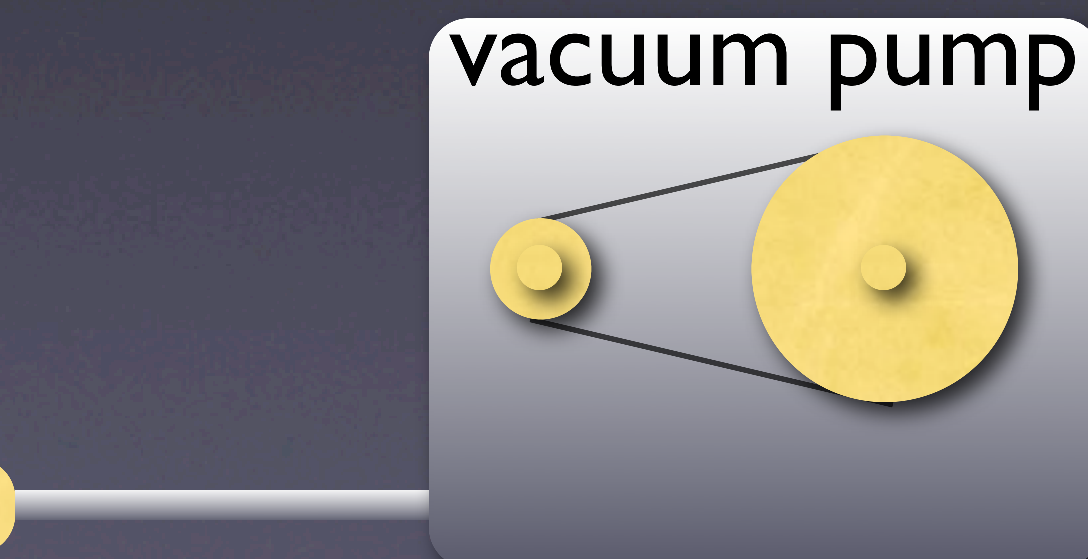
Boyle's Law: $P_1 x V_1 = P_2 x V_2$

Pressure and Volume are inversely proportional. Whatever you do to pressure, you do the inverse (reciprocal) to volume.

When using Boyle's Law, temperature is kept constant (not changed).



	Pressure	Volume	P x V
1	1.0 atm	200 mL	?



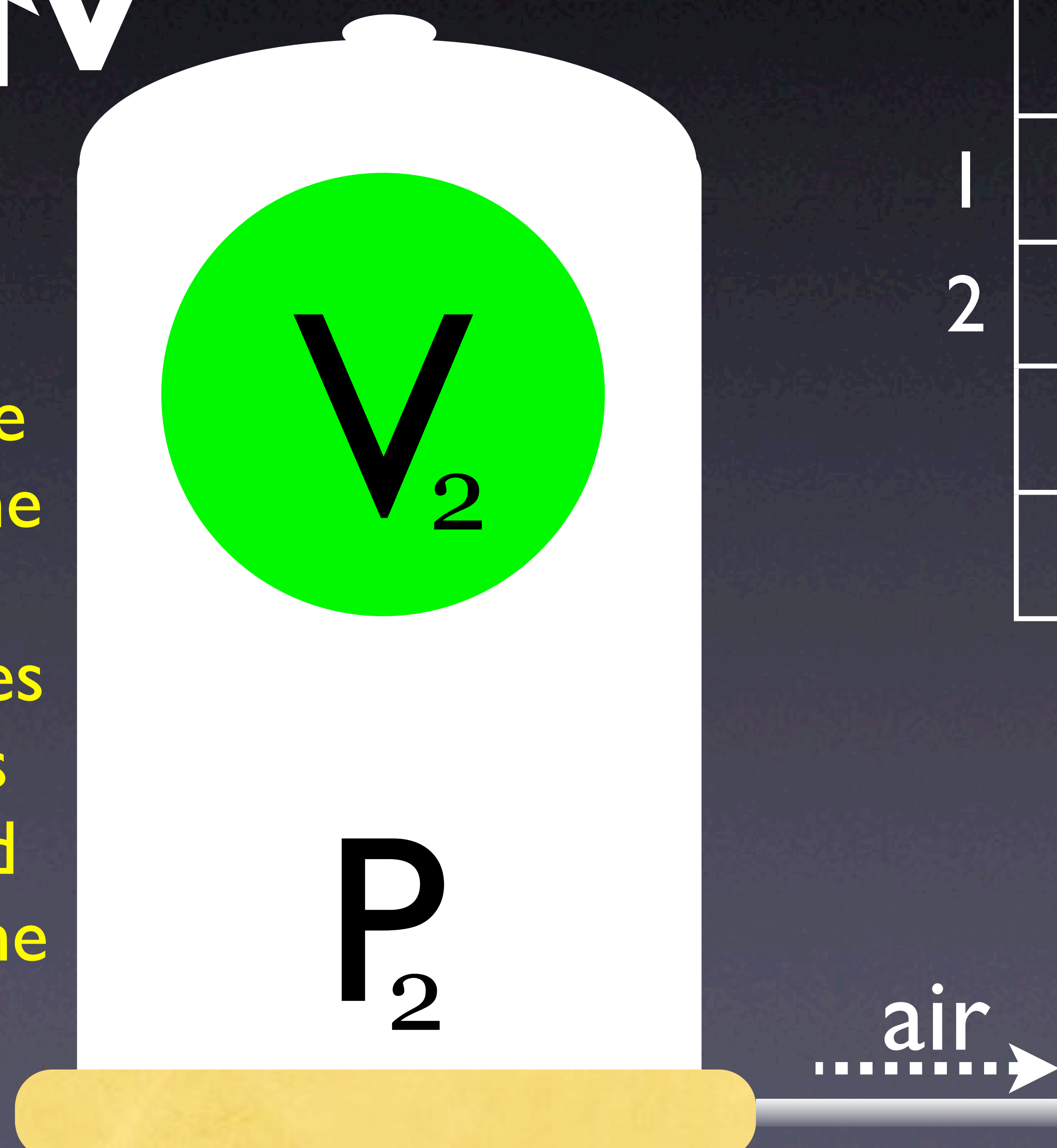
Boyle's Law: $P_1 x V_1 = P_2 x V_2$

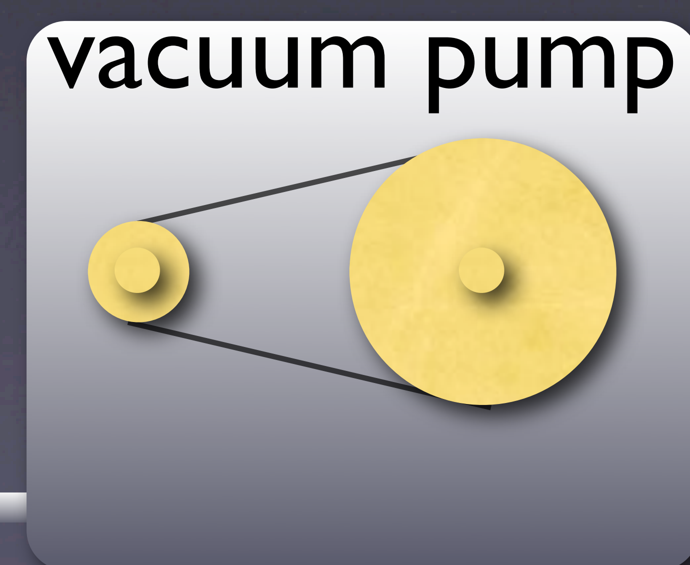
Pressure and Volume are inversely proportional. Whatever you do to pressure, you do the inverse (reciprocal) to volume.

↓P=↑V

	Pressure	Volume	P x V
1	1.0 atm	200 mL	200 atm • mL
2	0.5 atm	?	200 atm • mL

Pressure inside the bell jar decreases as air is pumped out of the jar.





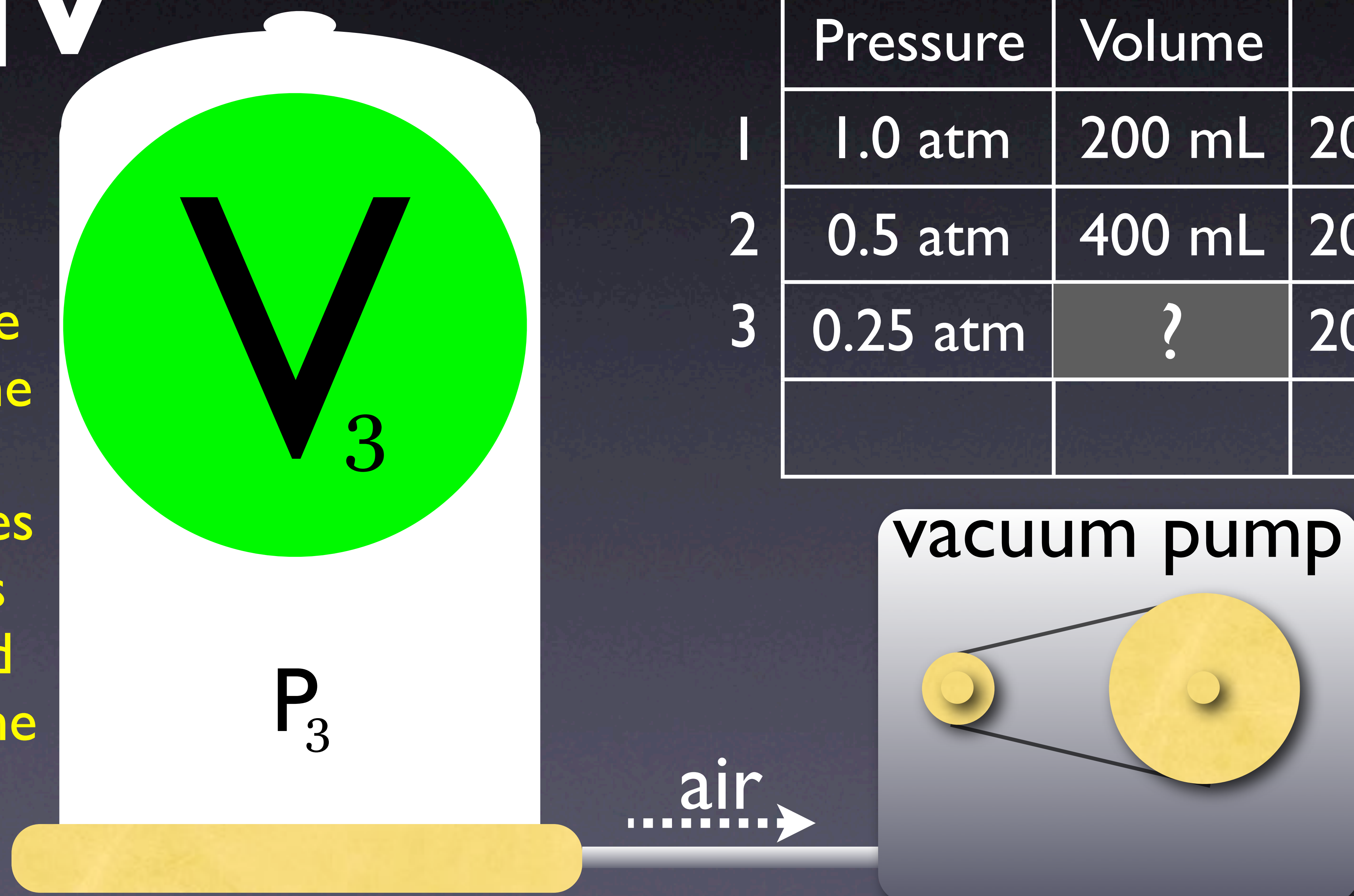
Boyle's Law: $P_1 x V_1 = P_2 x V_2$

Pressure and Volume are inversely proportional.
Whatever you do to pressure, you do the inverse (reciprocal) to volume.

↓P=↑V

	Pressure	Volume	P x V
1	1.0 atm	200 mL	200 atm • mL
2	0.5 atm	400 mL	200 atm • mL
3	0.25 atm	?	200 atm • mL

Pressure inside the bell jar decreases as air is pumped out of the jar.



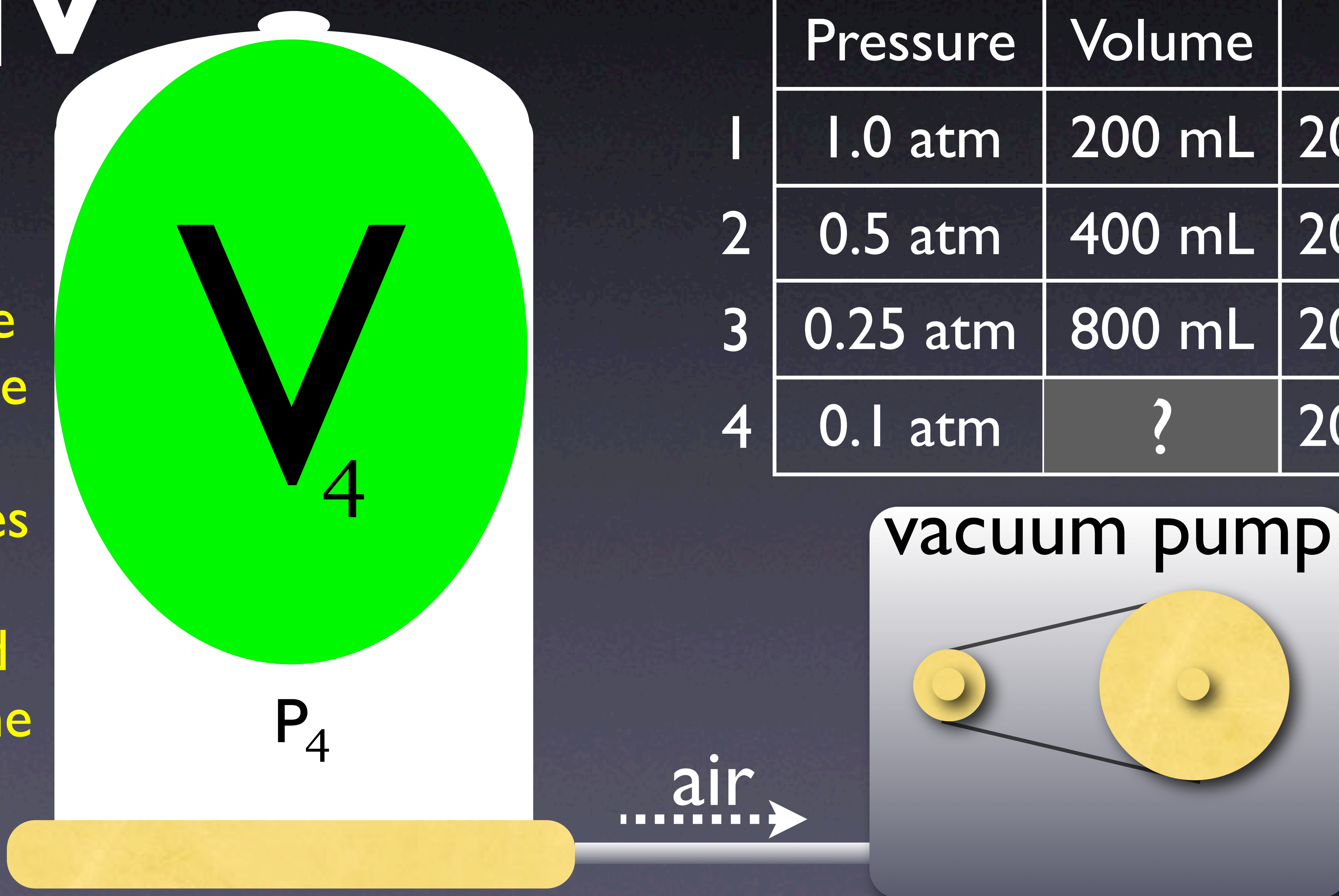
Boyle's Law: $P_1 x V_1 = P_2 x V_2$

Pressure and Volume are inversely proportional.
Whatever you do to pressure, you do the inverse (reciprocal) to volume.

↓P = ↑V

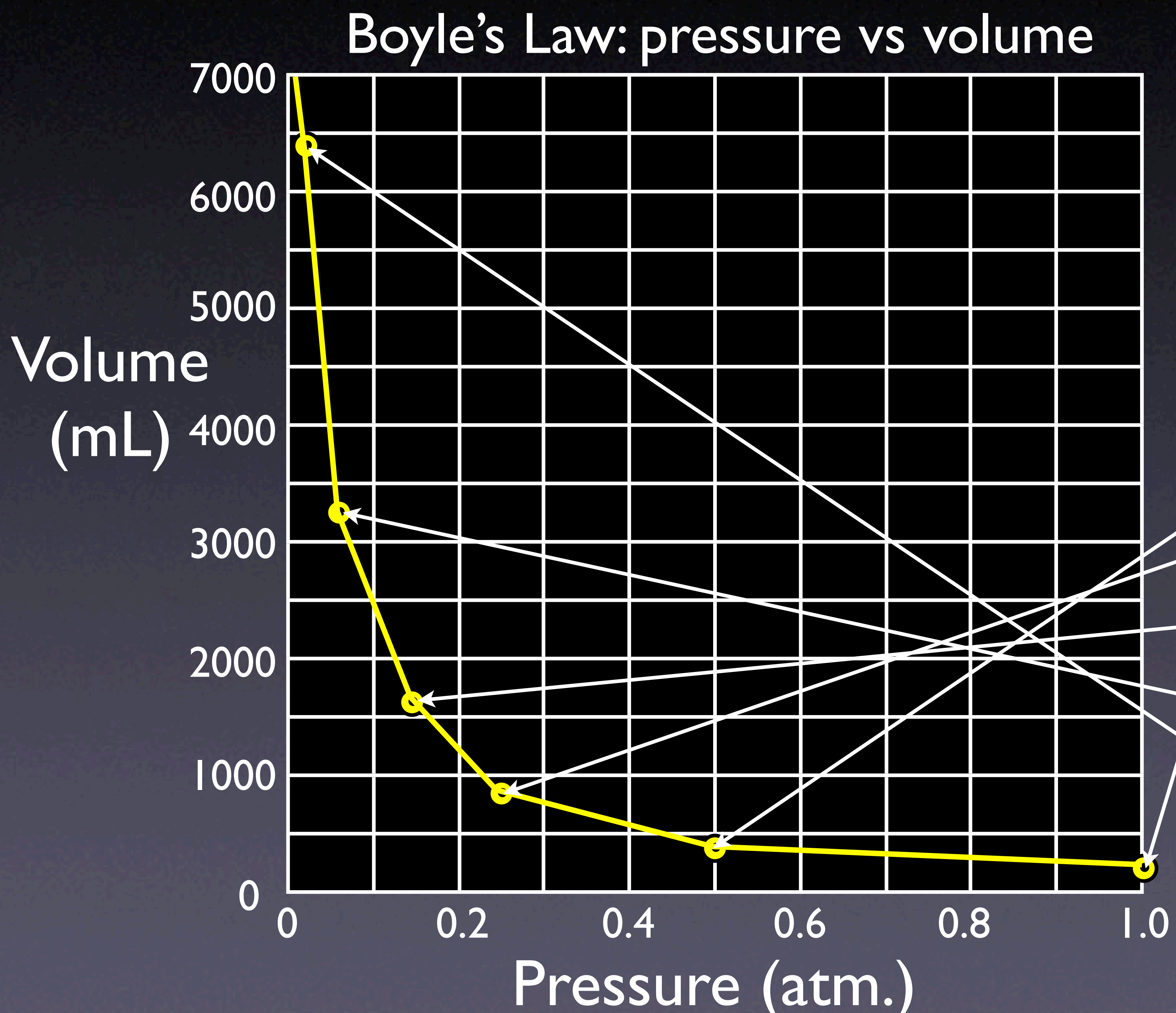
	Pressure	Volume	P x V
1	1.0 atm	200 mL	200 atm • mL
2	0.5 atm	400 mL	200 atm • mL
3	0.25 atm	800 mL	200 atm • mL
4	0.1 atm	?	200 atm • mL

Pressure inside the bell jar decreases as air is pumped out of the jar.



Graphing Bolye’s Gas Law

Whenever two variables are inversely proportional, the curve on a graph is always a hyperbola.



Pressure	Volume
1.0 atm	200 mL
0.5 atm	400 mL
0.25 atm	800 mL
0.13 atm	1600 mL
0.065 atm	3200 mL
0.033 atm	6400 mL

Speed & Time are inversely proportional.

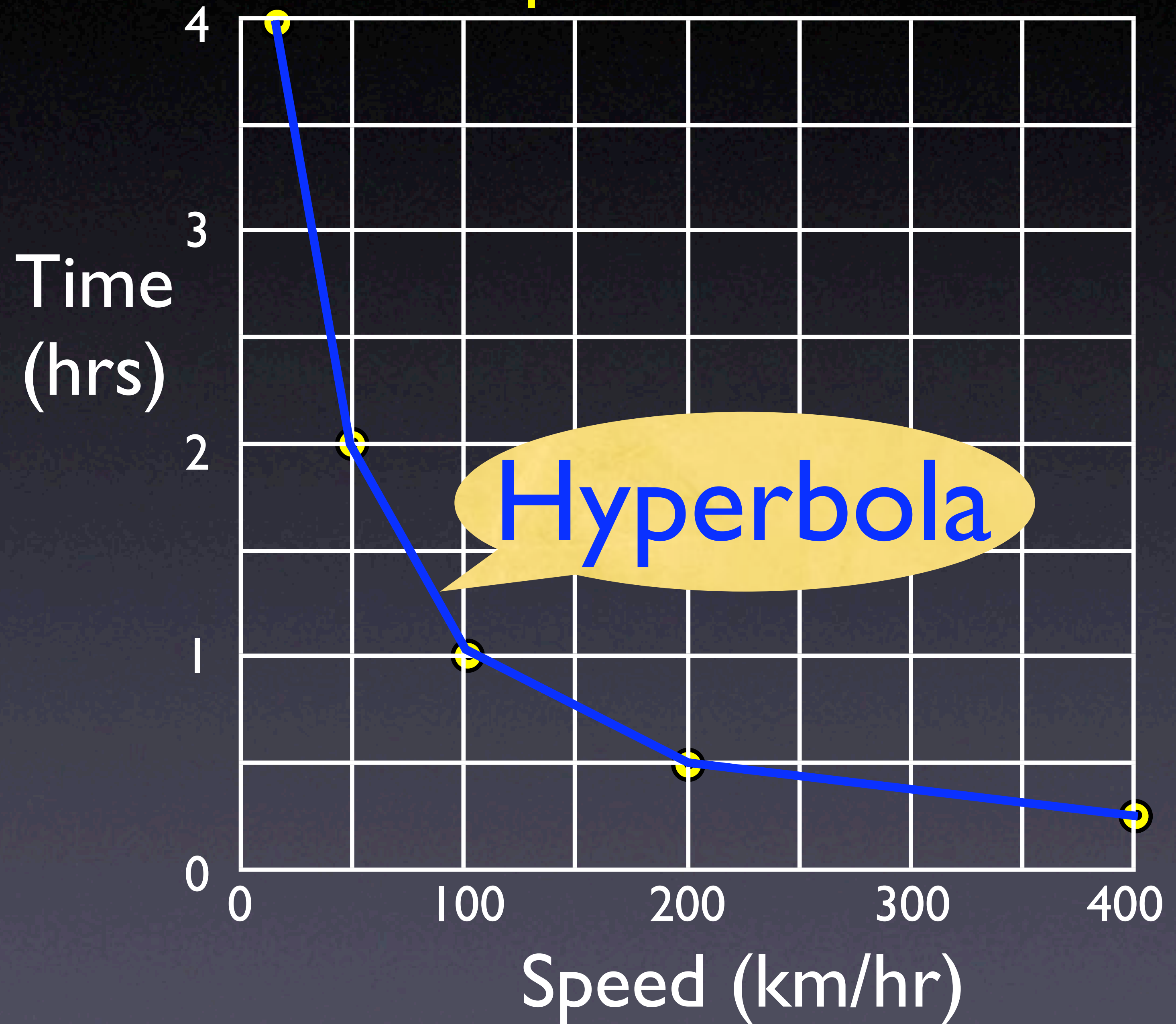
Speed and Time

Speed and time are inversely proportional when distance is kept constant.

Time required to drive 100 km

Speed (km/hr)	Time (hrs.)
25	4
50	2
100	1
200	.5
400	0.25

Speed vs. Time



Other variables that are inversely proportional:

Density and Volume

Density and Volume are inversely proportional when mass is kept constant.

Density of 1.0 gram of water

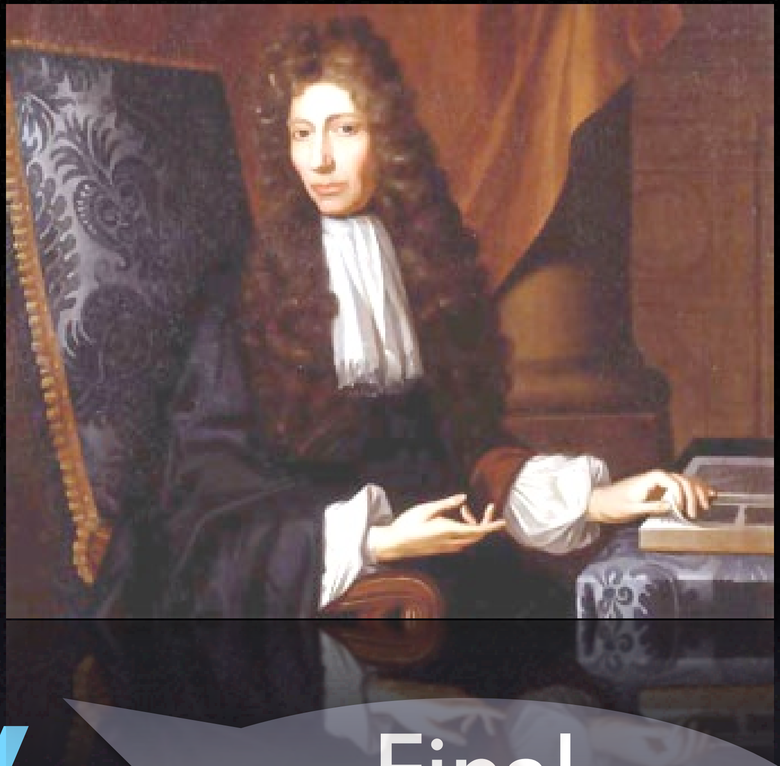
Volume	Density
1.0	1.0
2.0	0.5
4.0	0.25
8.0	0.125
16	0.067

$$A = \frac{B}{C}$$

If B is kept constant, A and C are always inversely proportional!

$$S = \frac{D}{T} \qquad D = \frac{M}{V} \qquad P = \frac{F}{A}$$

Boyle's Law



Pressure and volume are inversely proportional when temperature is kept constant.

Original (start with)

$$P_1 \times V_1 = P_2 \times V_2$$

Final (end with)

$$P_1 = \frac{P_2 \times V_2}{V_1}$$

$$P_2 = \frac{P_1 \times V_1}{V_2}$$

$$V_1 = \frac{P_2 \times V_2}{P_1}$$

$$V_2 = \frac{P_1 \times V_1}{P_2}$$

Boyle's Law Problem

A gas occupies a volume of 5.72 L at a pressure of 0.57 atm. Calculate the new volume of the gas when the pressure is increased to 4.23 atm while temperature remains constant.

Step 1 - Identify the variables.

V_1 = 5.72 L P_1 = 0.57 atm. V_2 = x P_2 = 4.23 atm.

Step 2 - Determine the formula required to solve for V_2.

$$V_2 = \frac{P_1 \times V_1}{P_2}$$

Step 3 - Plug the variables into the formula and solve.

$$V_2 = \frac{0.57\ \cancel{\text{atm.}} \times 5.72\ \text{L}}{4.23\ \cancel{\text{atm.}}} = 0.77\ \text{L}$$

Step 4 - Does this answer make sense?

Fun with Boyle's Law

What would happen if you put a marshmallow into the vacuum bell jar and pumped out the air?

Kelvin Temperature Scale

The Celsius temperature scale is based on the freezing point of water (0˚C).

The Kelvin scale is based on motion of the particles in matter - when all motion stops the temperature is 0 K.

While they are different scales, 1˚C = 1 K.

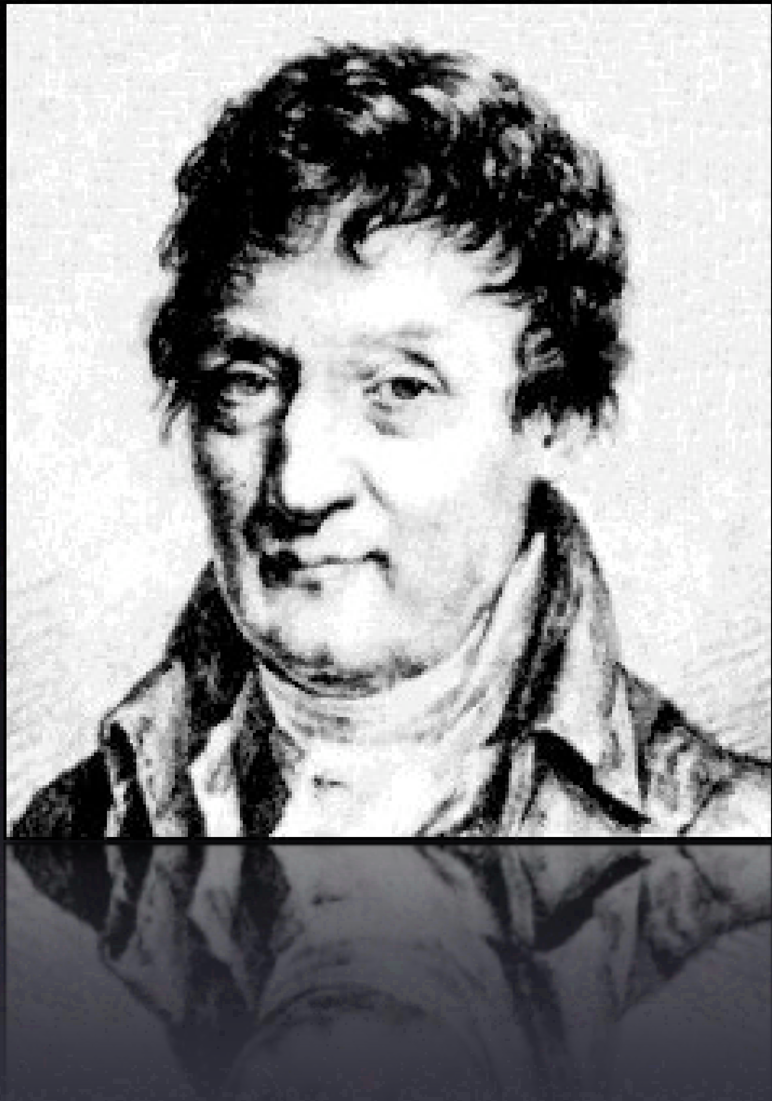
To convert Celsius to Kelvin you add 273.

To convert Kelvin to Celsius you subtract 273.

(An easy way to remember this is that you cannot have negative Kelvin temperature - you always add to get Kelvin).

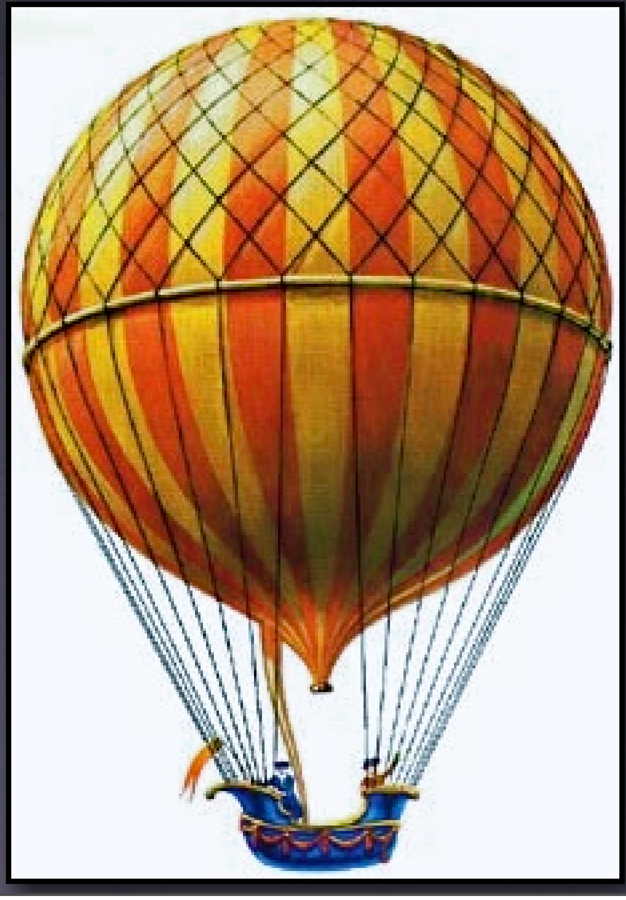
Event	Celsius	Kelvin
All motion stops	- 273˚C	0 K
Water freezes	0˚C	273 K
Room temp.	20˚C	293 K
Water boils	100˚C	373 K

Charles' Law



Jacques Charles
(1747-1823)

Born in France in 1747, Jacques was an avid balloonist. Jacques invented the hydrogen balloon in 1783 attained an altitude of 1,800 feet. Upon landing his balloon outside of Paris, a terrified mob of farmers, believing the balloon to be a monster, attacked and destroyed it with their pitchforks.



Jacques became interested in the relationship between the volume and temperature of a gas when pressure is kept constant.

From experimentation he discovered that the volume and temperature of a gas are directly proportional when pressure is kept constant.

From this he was able to conclude that $V_1/T_1 = V_2/T_2$

Charles' Law

Charles discovered that temperature and volume of a gas are directly proportional when pressure is kept constant.

When two variables are directly proportional, whatever you do to one you do to the other.

Double one variable, the other doubles.

Cut one variable to 1/3, the other is cut to 1/3.

Other variables that are directly proportional:

mass & weight: double mass & weight doubles

speed & distance: cut speed in half and distance traveled is cut in half.

Charles' Law

You must do two things before you can use Charles' Law:

1. Use the Kelvin scale for temperature. The Celsius scale will not work in any gas law.

2. Cross multiply to rearrange the formula horizontally.

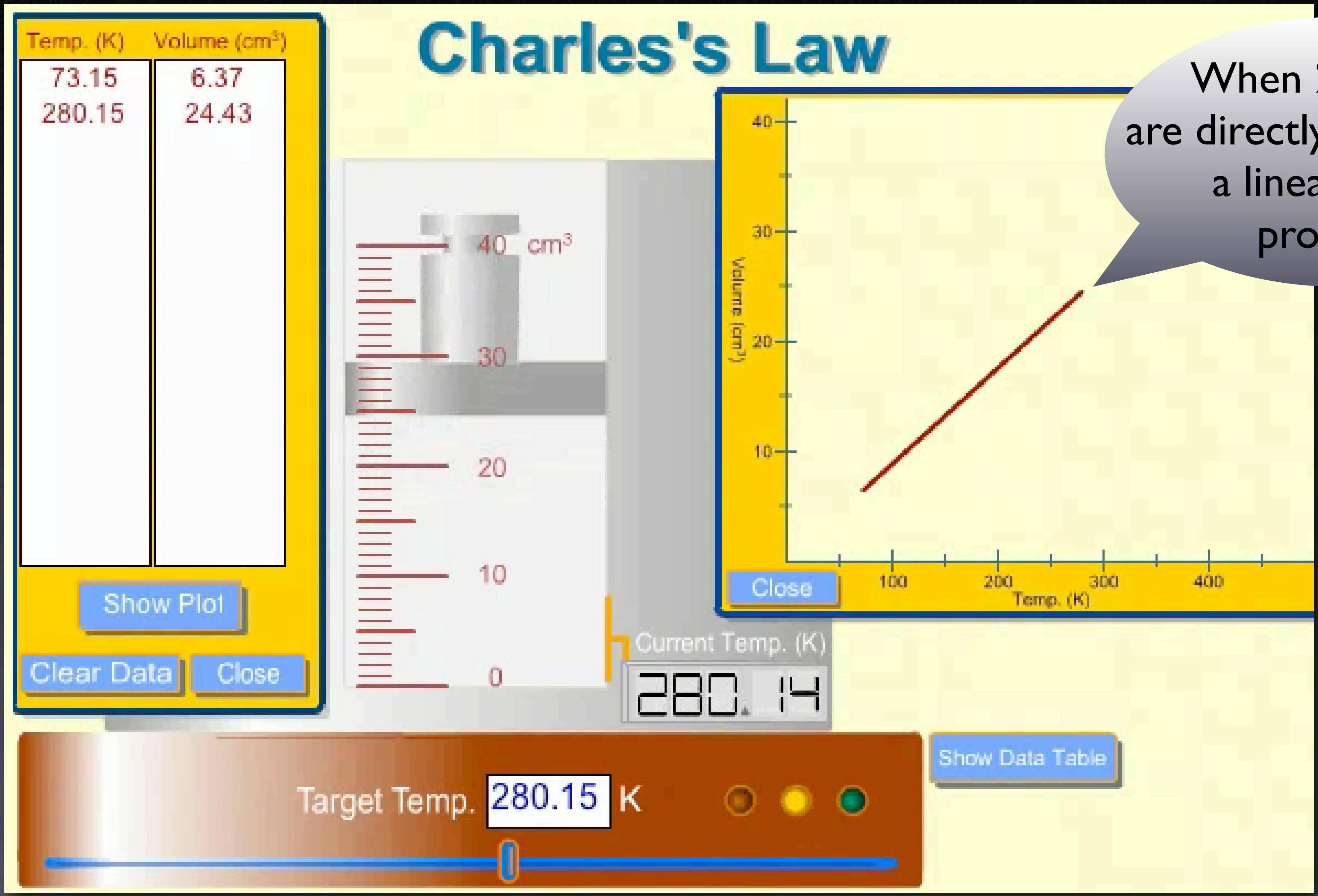
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Cross multiply and you get:

$$V_1 \times T_2 = T_1 \times V_2$$

Charles' Law Problem

A gas at 73.15 K with a volume of 6.37 cc is heated to 280.15 K while pressure is kept constant.
What is the new volume of the gas?



When 2 variables are directly proportional a linear curve is produced.

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Charles' Law Problem

A gas at 73.15 K with a volume of 6.37 cc is heated to 280.15 K while pressure is kept constant.
What is the new volume of the gas?

Step 1 - Identify the variables.

$T_1 = 73.15$ K $V_1 = 6.37$ cc $T_2 = 280.15$ K $V_2 = x$

Step 2 - Determine the formula required to solve for V_2.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

cross multiply to get:

$$V_1 \times T_2 = V_2 \times T_1$$

divide both sides of the equation by T_1 to isolate V_2

$$V_2 = \frac{V_1 \times T_2}{T_1}$$

Step 3 - Plug the variables into the formula and solve.

$$V_2 = \frac{6.37 \text{ cc} \times 280.15 \not{\text{K}}}{73.15 \not{\text{K}}} = 24.4 \text{ cc}$$

Step 4 - Does this answer make sense?

Gay-Lussac's Law

Joseph Gay-Lussac

(1778-1850)

Joseph Gay-Lussac was born in France in 1778. Like Jacques Charles, Joseph took up an interest in ballooning.

In 1804 he made the first scientific balloon ascent in a hydrogen balloon, rising to an altitude of 2.5 miles. He did so to observe the earth's magnetic field and the composition of the atmosphere at high altitudes.

Later that same year he made another journey - one that almost cost him his life. Reaching an altitude over 4 miles the temperature dropped below freezing.

Joseph was not dressed for the occasion - during his six hours aloft, he almost froze to death.

Joseph began experimenting with gasses and in 1805 discovered the relationship between temperature and pressure. His law states that temperature and pressure are directly proportional when volume is kept constant.

From experimentation he concluded that $P_1/T_1 = P_2/T_2$.

Gay-Lussac's Law

Pressure and Temperature are directly proportional when volume is constant.

*temperature must be in Kelvin

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Rearranged: $P_1 \times T_2 = P_2 \times T_1$

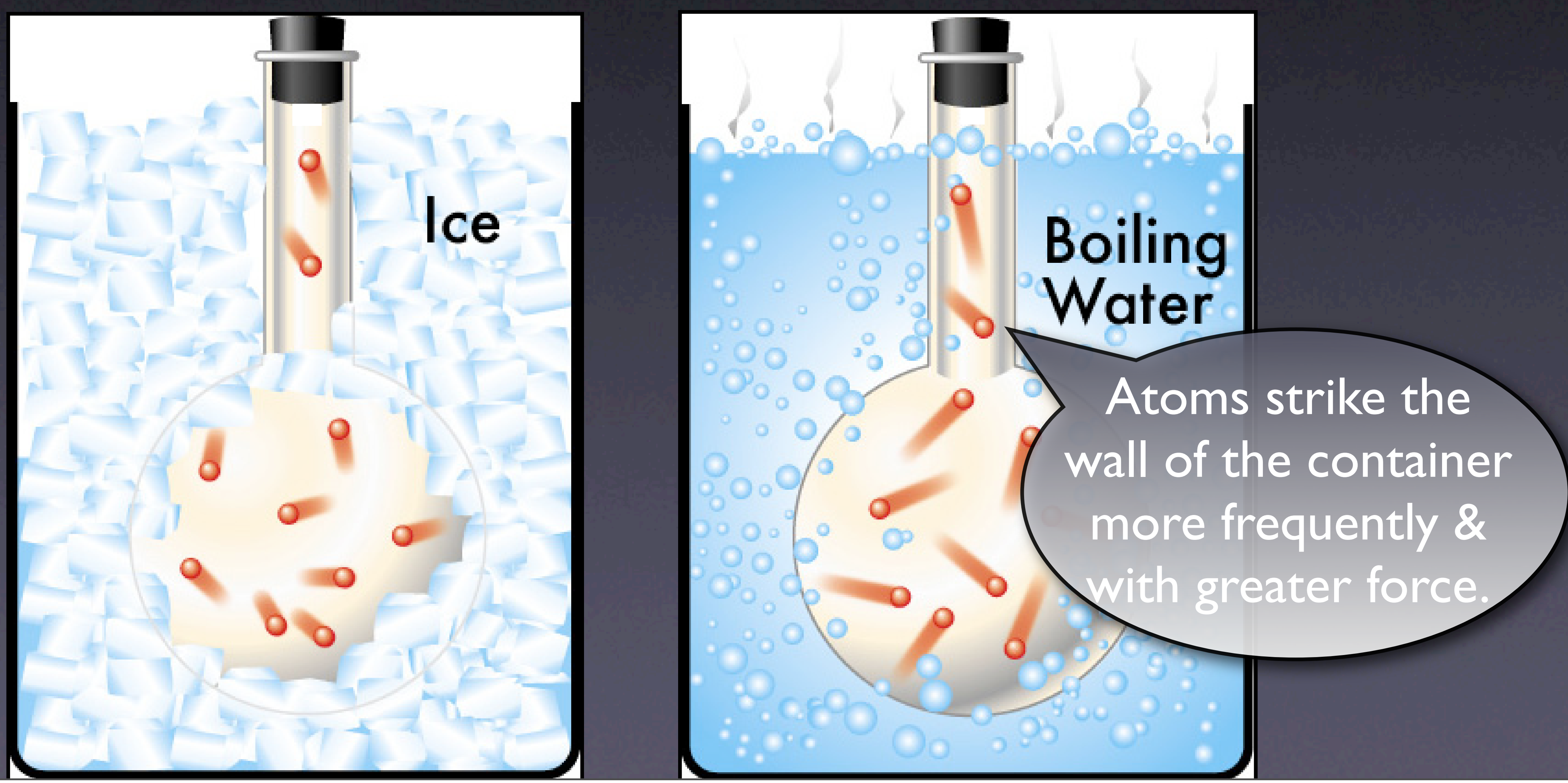
As a gas is heated, the particles (atoms or molecules) gain kinetic energy and move faster and further.

As heat energy increases the particles strike the wall of the container more frequently and with a greater force and therefore increasing the pressure of the gas.

Gay-Lussac’s Law

Pressure and Temperature are directly proportional when volume is constant.

*temperature must be in Kelvin



Gay-Lussac's Law

Just as in Charles' Law, you must do two things before using Gay-Lussac's Law:

1. Use the Kelvin scale for temperature. The Celsius scale will not work in any gas law.

2. Cross multiply to rearrange the formula horizontally.

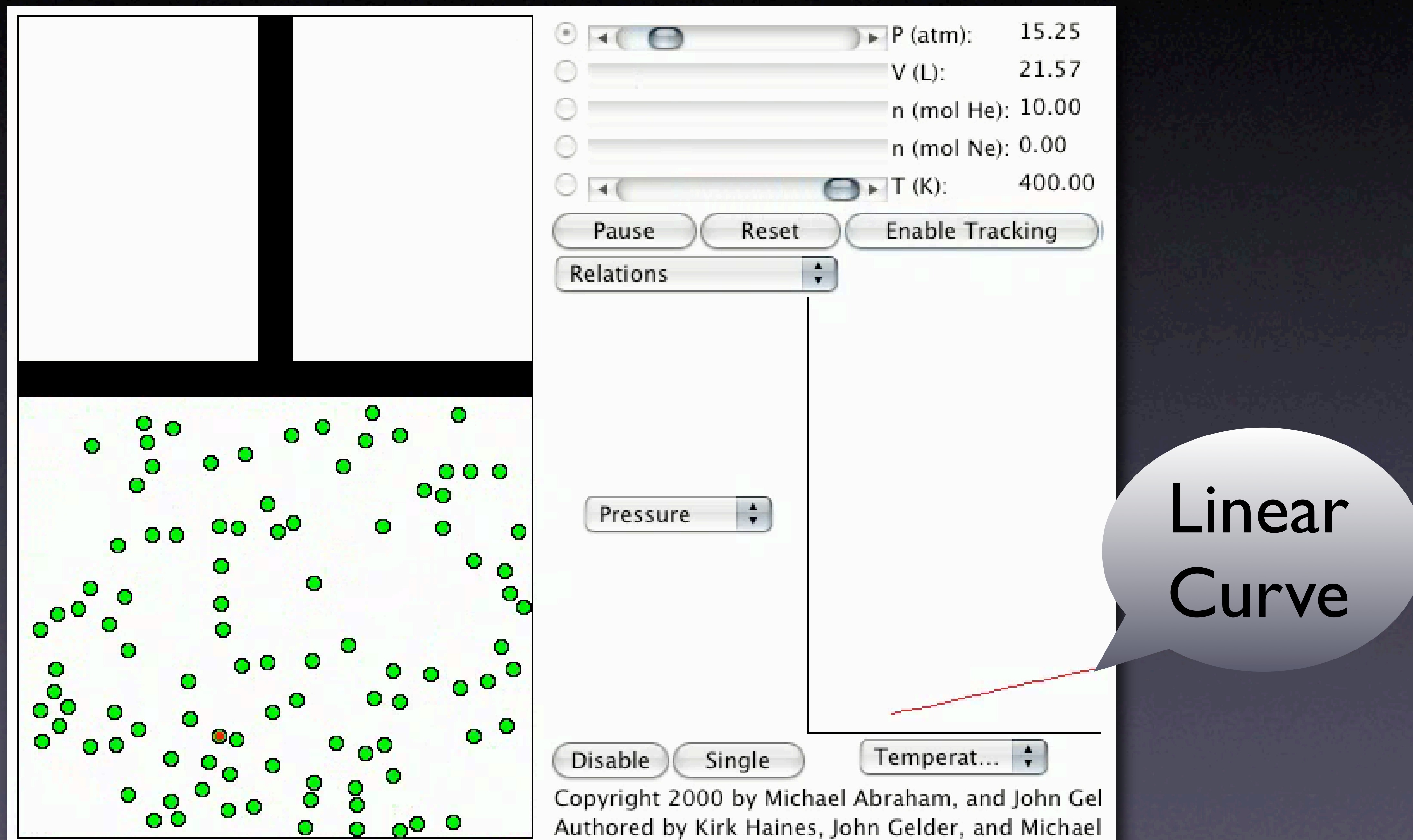
$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Cross multiply and you get:

$$P_1 \times T_2 = T_1 \times P_2$$

Gay-Lussac's Law Problem

A gas at -173˚C with a pressure of 3.81 atm. is heated to 127˚C while the volume is kept constant. What is the new pressure of the gas?



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Gay-Lussac's Law Problem

A gas at -173°C with a pressure of 3.81 atm. is heated to 127°C while the volume is kept constant. What is the new pressure of the gas?

Step 1 - Convert Celsius temperatures to Kelvin.

$T_1 = -173°C + 273 = 100.\,K$ $T_2 = 127°C + 273 = 400.\,K$

Step 2 - Identify the variables.

$T_1 = 100.\,K$ $P_1 = 3.81\text{ atm}$ $T_2 = 400.\,K$ $P_2 = x$

Step 2 - Determine the formula required to solve for P_2.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

cross multiply to get:

$$P_1 \times T_2 = P_2 \times T_1$$

divide both sides of the equation by T_1 to isolate P_2

$$P_2 = \frac{P_1 \times T_2}{T_1}$$

Step 3 - Plug the variables into the formula and solve.

$$P_2 = \frac{3.81\text{ atm} \times 400.\,\cancel{K}}{100.\,\cancel{K}} = 15.24\text{ atm}$$

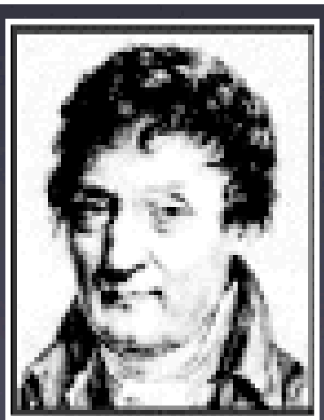
Step 4 - Does this answer make sense?

Which Gas Law do I use?

In each gas law one variable is constant and therefore does not show up in the formula. That will tell you which gas law to use.

If temperature is constant use Boyle's law:

$$P_1 \times V_1 = P_2 \times V_2$$



If pressure is constant use Charles' law:

$$V_1 / T_1 = V_2 / T_2$$

If volume is constant use Gay-Lussac's law:

$$P_1 / T_1 = P_2 / T_2$$

Any Questions?