Unit 6 Phases of Matter
-Ideal Gas

Ideal Gas Law

- A gas that follows this relationship is known as an ideal gas.

$$\boldsymbol{PV = nRT}$$

P = Pressure
V = Volume
n = number of moles
R = gas constant
T = Temperature **in K**

Unless told otherwise in CHEM 154 assume all gases behave ideally.

- Generally gases at high temperatures and low pressures can be described by the ideal gas law.

Useful Constants

Pressure

1 atm = 760 mmHg = 760 Torr = 101325 Pa

1 bar = 100000 Pa = 0.986923 atm

Gas constant

$R = 0.082057\ (\mathrm{L \cdot atm \cdot mol^{-1} \cdot K^{-1}})$

$= 0.083145\ (\mathrm{L \cdot bar \cdot mol^{-1} \cdot K^{-1}})$

$= 8.3145\ (\mathrm{J \cdot mol^{-1} \cdot K^{-1}})$

$= 62.364\ (\mathrm{L \cdot torr \cdot mol^{-1} \cdot K^{-1}})$

Convert R

- Pressure is often reported in a variety of different units.

1 atm = 760 mmHg = 760 Torr = 101325 Pa

100000 Pa = 1 bar

- In SI units, the molar gas constant R= 8.3145 J mol^{-1} K^{-1}
- Work through the conversion of R to **L ·atm · mol^{-1} · K^{-1}** and **L · torr · mol^{-1} · K^{-1}**

Clicker Question

A <u>2.650-g</u> sample of a gas occupies a volume of <u>428 mL</u> at <u>0.9767 atm</u> and <u>297.3 K</u>. What is its molar mass?

a) 97.5 g/mol

b) 123 g/mol

c) 155 g/mol

d) 186 g/mol

Clicker Question

A 2.650-g sample of a gas occupies a volume of 428 mL at 0.9767 atm and 297.3 K. What is its molar mass?

a) 97.5 g/mol

b) 123 g/mol

✓ c) 155 g/mol

d) 186 g/mol

Use $n \equiv \dfrac{W}{MW}$

$$PV = nRT$$

$$\Rightarrow PV = \frac{W}{MW}RT$$

$$\Rightarrow 0.9767\ (\text{atm}) \cdot 0.428\ (\text{L}) = \frac{2.650\ (\text{g})}{\text{MW}} \cdot 0.082057\ (\text{L} \cdot \text{atm} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}) \cdot 297.3\ \text{K}$$

$$\Rightarrow \text{MW} = 155 (\text{g/mol})$$

Clicker Question

A 5.00 L container of unknown gas at 25.0 °C has a pressure of 2.45 atm. The mass of the gas is 32.1 g. What gas is in the container?

a) Cl_2
b) F_2
c) NO_2
d) SO_3
e) SO_2

Clicker Question

A 5.00 L container of unknown gas at 25.0 °C has a pressure of 2.45 atm. The mass of the gas is 32.1 g. What gas is in the container?

a) Cl_2
b) F_2
c) NO_2
d) SO_3
✓e) SO_2

Molar masses:
A = Cl_2 = 70.906
B = F_2 = 37.997
C = NO_2 = 46.0055
D = SO_3 = 80.066
E = SO_2 = 64.066

Clicker Question

A <u>50.0 mL</u> canister of Freon-12 (CF_2Cl_2) was heated in boiling water (<u>100.0 °C</u>) until the canister burst. If the canister was not defective, and had a burst rating of <u>102.05 atm</u>, what minimum amount of Freon-12 was in the canister, assuming no volume change before bursting?

a) 9.63 g
b) 11.5 g
c) 20.2 g
d) 27.5 g
e) 75.0 g

1 atm = 760 mmHg = 760 Torr = 101325 Pa;

100000 Pa = 1 bar

R = 0.082057 L atm mol^{-1} K^{-1} = 8.3145 J mol^{-1} K^{-1} = 62.364 L torr mol^{-1} K^{-1}

STP: T = 273.15 K (0 Celsius) , P = 1 bar

Clicker Question

A 50.0 mL canister of Freon-12 (CF_2Cl_2) was heated in boiling water (100.0 °C) until the canister burst. If the canister was not defective, and had a burst rating of 102.05 atm, what minimum amount of Freon-12 was in the canister, assuming no volume change before bursting?

a) 9.63 g
b) 11.5 g
c) 20.2 g
d) 27.5 g
e) 75.0 g

$$PV = nRT$$

$$\Rightarrow PV = \frac{W}{MW} RT$$

$$\Rightarrow 102.05 \cdot 0.05 = \frac{\mathrm{W}}{121} \cdot 0.082057 \cdot 373.3$$

$$\Rightarrow W = 20.2(\mathrm{g})$$

Dalton's Law of Partial Pressures

– For a mixture of gases in a container of volume V, the total pressure is the sum of the partial pressures of each gas.

$$P_{\text{total}} = P_1 + P_2 + P_3 + \ldots$$

– Partial pressure: pressure a gas would exert if it were alone.

– For ideal gases,

$$P_{\text{total}}\, V = (n_1 + n_2 + n_3 + \ldots)\, RT$$

Mole fraction

- The mole fraction (x) is the ratio of the number of moles of a given component in a mixture to the total number of moles of the mixture

- $x_1 \equiv \frac{n_1}{n_{total}} = \frac{n_1}{n_1+n_2+n_3+\cdots}$

- Consequently for ideal gases,

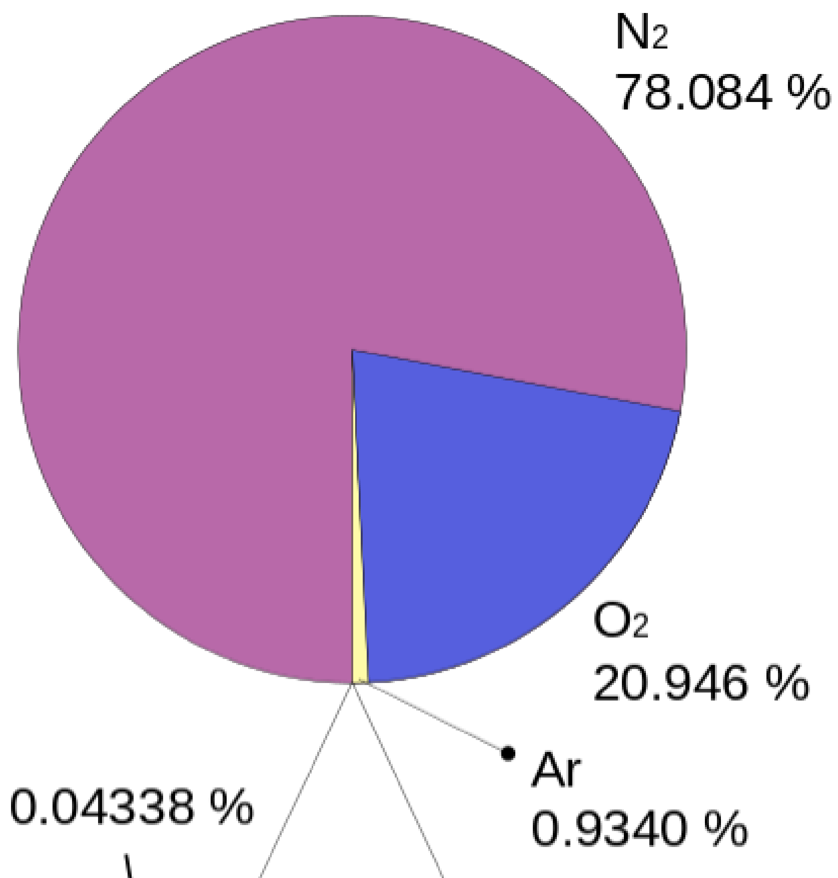
$$x_1 \equiv \frac{n_1}{n_{total}} = \frac{P_1}{P_{total}}$$

- **Mole fraction is unitless and always be between 0 and 1.**

Clicker Question

The mole fraction of N_2 in air is 0.781. Given the atmospheric pressure of 760 Torr, calculate the partial pressure of N_2 in air.

a) 781 Torr
b) 593 Torr
c) 394 Torr
d) 167 Torr
e) 973 Torr



Clicker Question

The mole fraction of N_2 in air is 0.781. Given the atmospheric pressure of 760 Torr, calculate the partial pressure of N_2 in air.

a) 781 Torr

b) 593 Torr $P_{N_2} = 760\ (\text{Torr}) \cdot 0.781 = 593.6\ (\text{Torr})$

c) 394 Torr

d) 167 Torr

e) 973 Torr

Clicker Question

A mixture consisting of 4.9 g CO and 8.5 g SO_2, two atmospheric pollutants, exerts a pressure of 0.761 atm when placed in a sealed container. What is the partial pressure of the SO_2 in this mixture?

a) 0.13 atm
b) 0.18 atm
c) 0.33 atm
d) 0.43 atm

Clicker Question

A mixture consisting of 4.9 g CO and 8.5 g SO_2, two atmospheric pollutants, exerts a pressure of 0.761 atm when placed in a sealed container. What is the partial pressure of the SO_2 in this mixture?

a) 0.13 atm
b) 0.18 atm
c) 0.33 atm ✓
d) 0.43 atm

$$n_{CO} = \frac{W}{MW} = \frac{4.9(g)}{28(g)} = 0.175$$

$$n_{SO_2} = \frac{W}{MW} = \frac{8.5}{64.1} = 0.133$$

Use $P_{SO_2} = \frac{n_{SO_2}}{n_{CO} + n_{SO_2}} \cdot P_{total}$

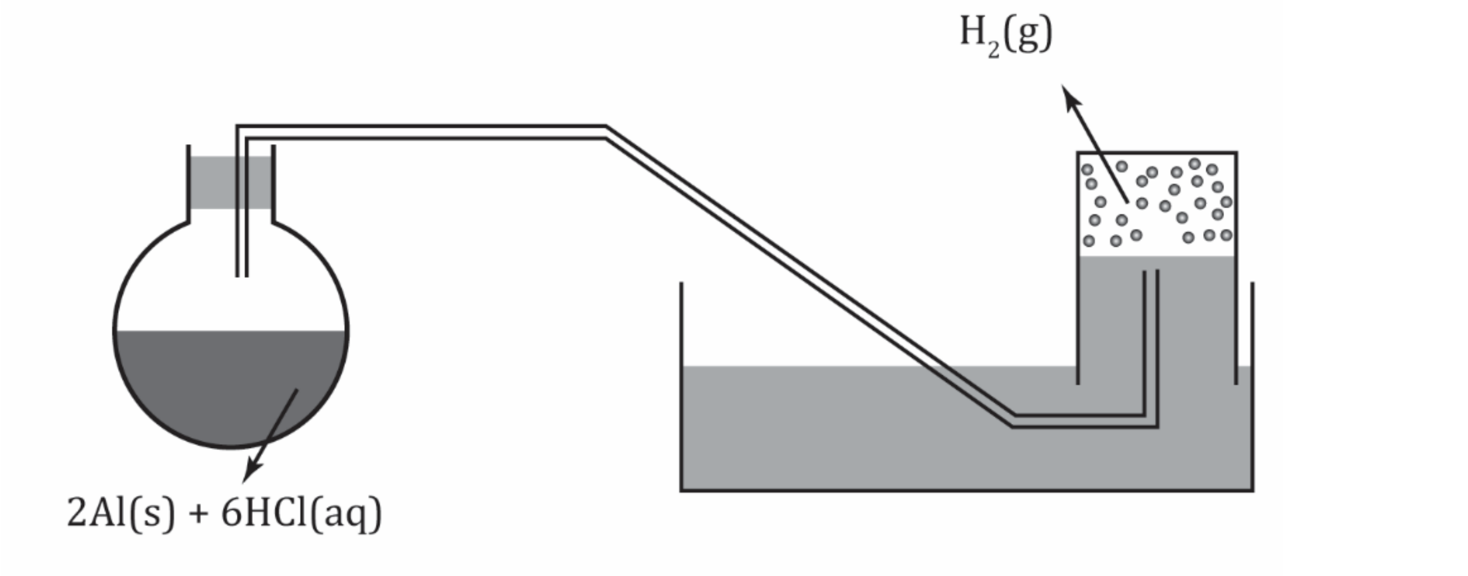
$= \frac{0.133}{0.175 + 0.133} \cdot 0.761$ (atm)

=0.329 (atm)

Worksheet Question #9

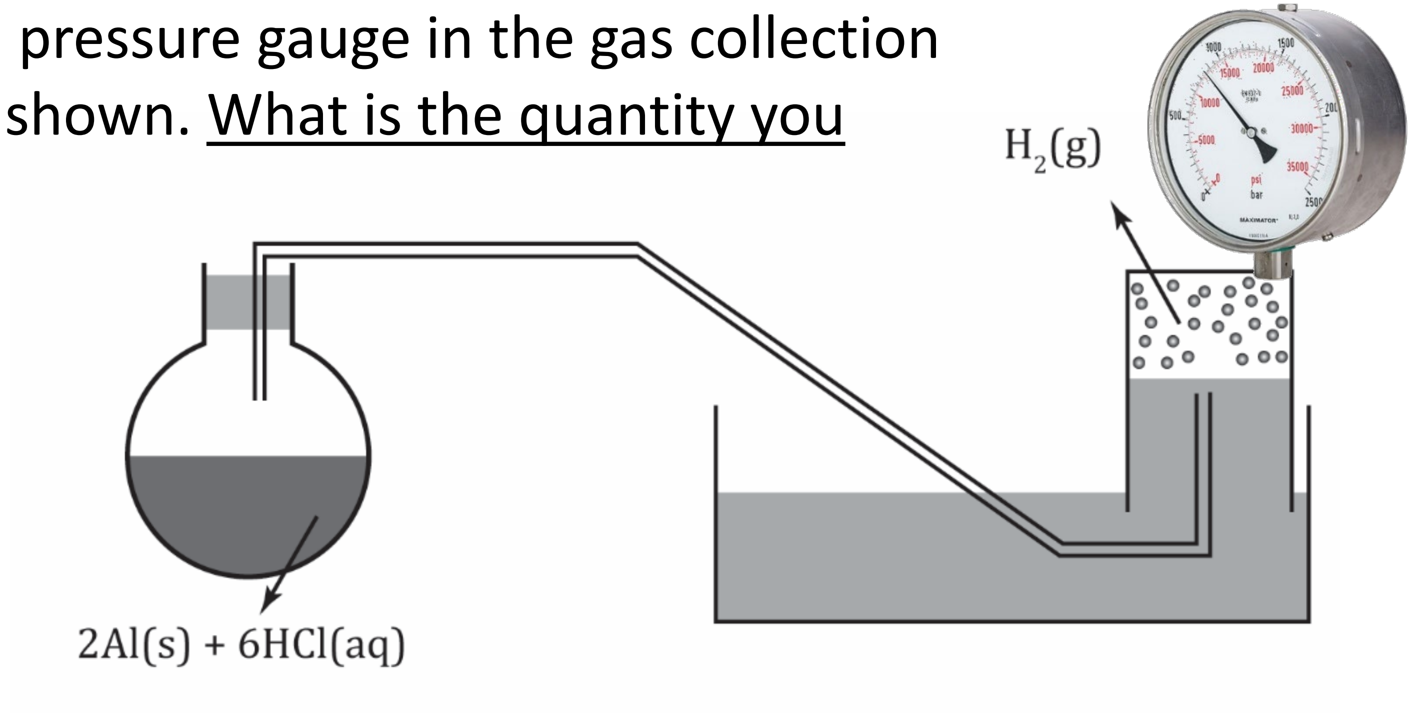
The reaction of aluminum with HCl produces hydrogen gas: <u>35.5 mL of H_2</u> is collected in a sealed container over water at <u>26 °C</u> and the pressure is measured to be <u>755 mmHg</u>, how many moles of H_2 were produced? (The <u>vapour pressure of water at 26 °C is 25.2 mmHg</u>).

$$2Al_{(s)} + 6HCl_{(aq)} \rightarrow 2AlCl_{3(aq)} + 3H_{2(g)}$$



Clicker

The experimental apparatus for WS Q2 is shown. You have a pressure gauge in the gas collection volume as shown. <u>What is the quantity you measure?</u>



A. Total pressure

B. Pressure of the H_2 gas evolved

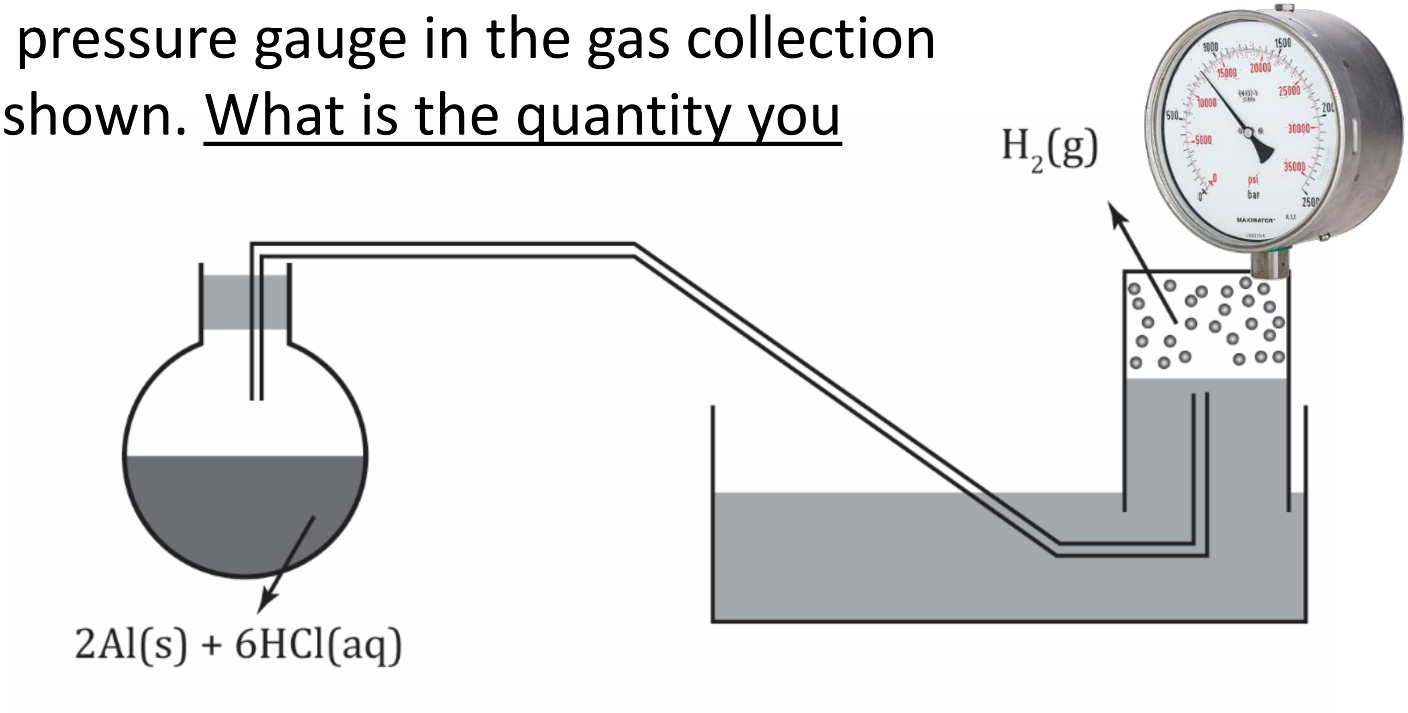
C. H_2O vapour pressure

D. Atmospheric pressure

E. Unrelated to the experiment, why are you doing this?

Clicker

The experimental apparatus for WS Q2 is shown. You have a pressure gauge in the gas collection volume as shown. <u>What is the quantity you measure</u>?



✓ A. Total pressure (both water vapor and H_2)
B. Pressure of the H_2 gas evolved
C. H_2O vapor pressure
D. Atmospheric pressure
E. Unrelated to the experiment, why are you doing this?

Real gases

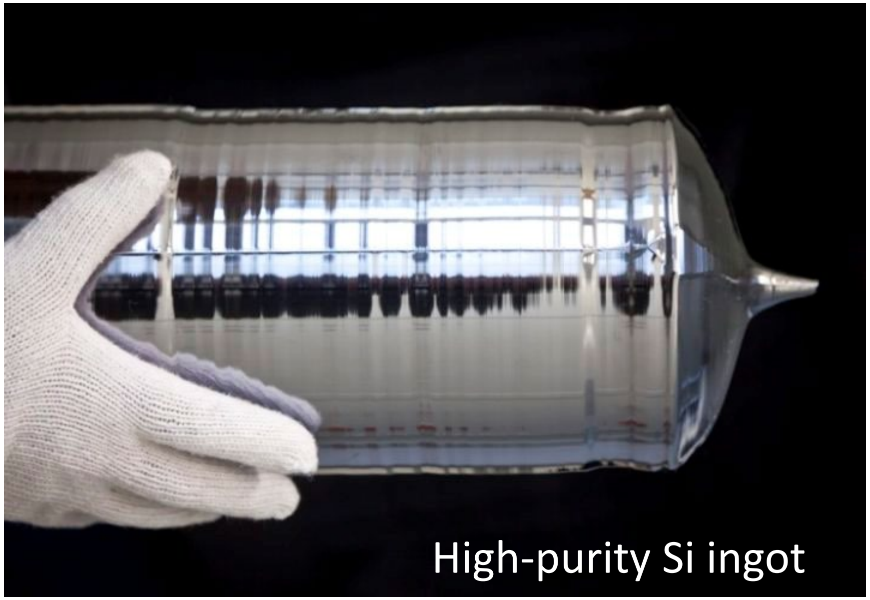
- The ideal gas model assumes molecules do not interact. Real molecules **do** have interactions.

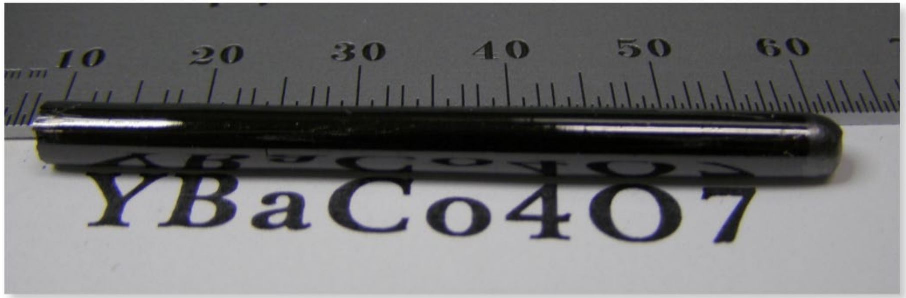
- At low densities (low pressure), molecules in the gas spend little time close together so the effect of any interactions is negligible and the ideal gas equation can be quite accurate.

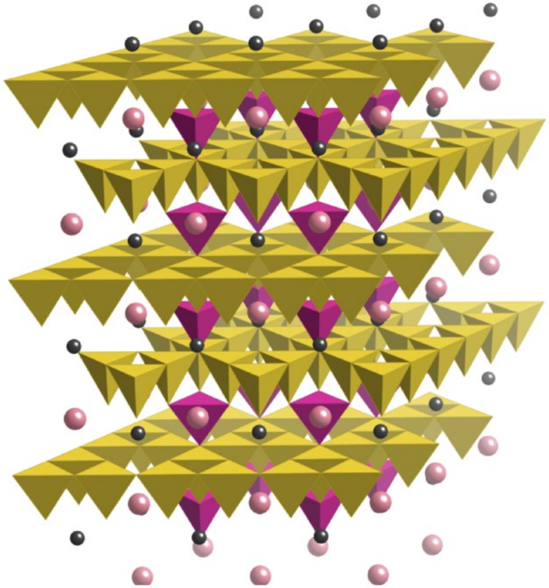
- At high densities (high pressure), interactions start to have an effect and more accurate gas equations are needed, such as the virial equation or the van der Waals equation.

Blueprint question

Where can we find next-gen materials?







Many believe the next technological leap will come from more complex materials where electrons interact strongly
Strong effort here at UBC, including crystal growth!

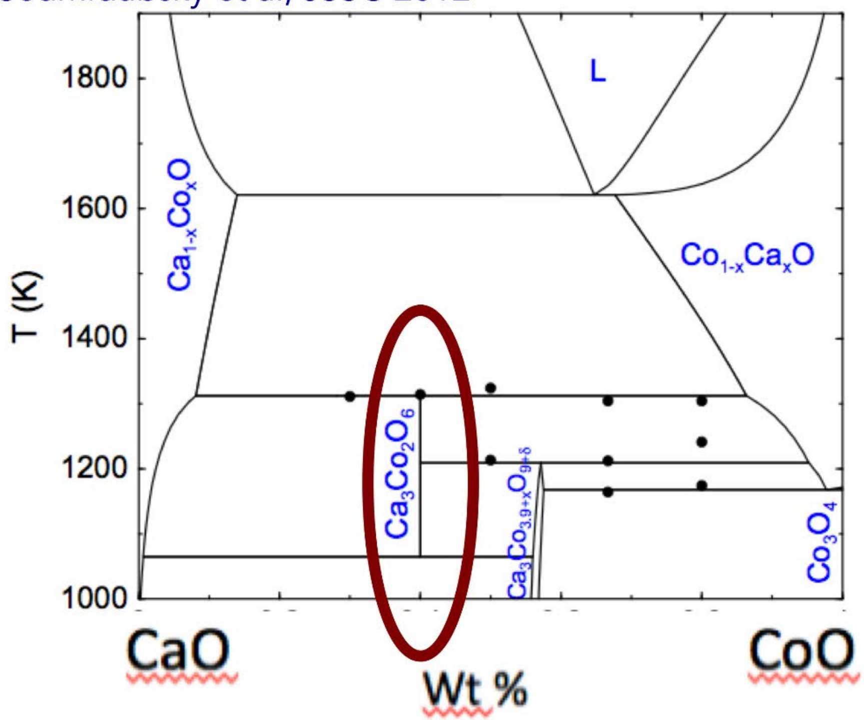
Blueprint question

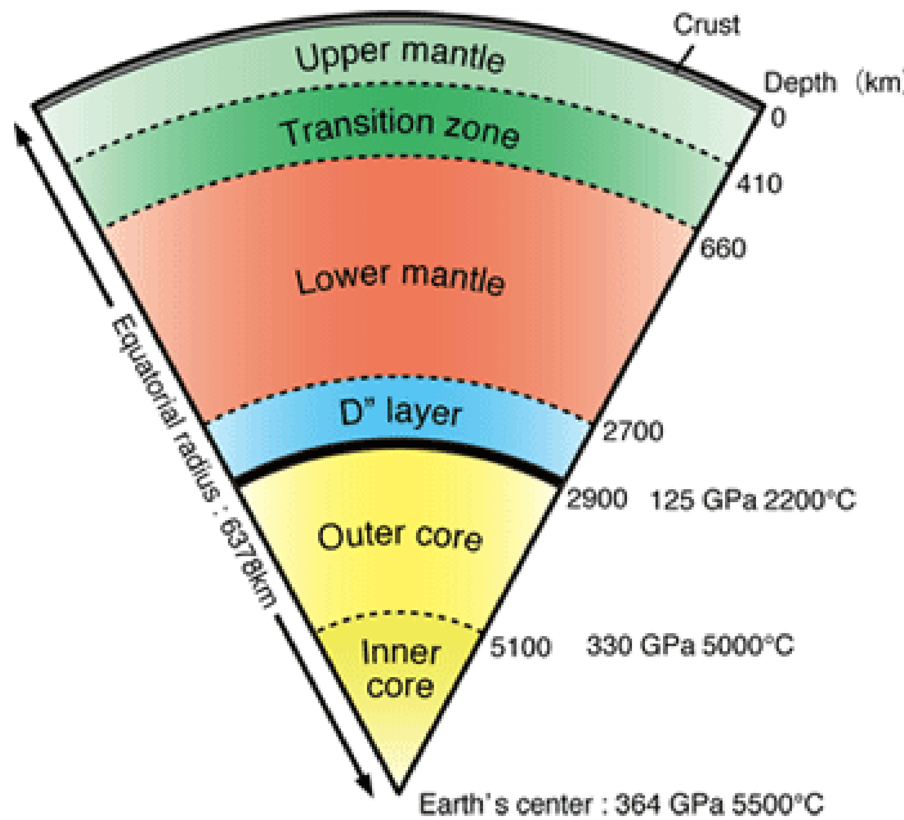
Typical crystal growth knobs:
temperature & composition

Geology also uses pressure!

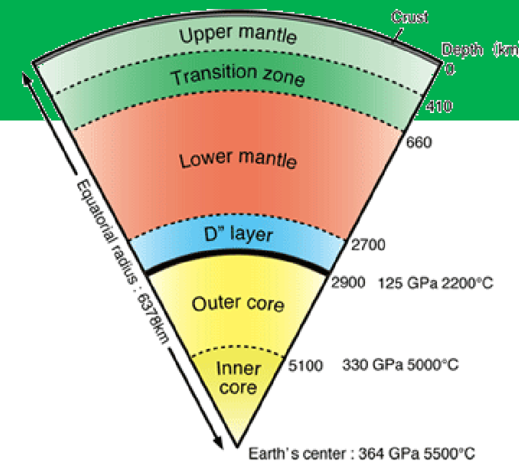
pO_2 = 1 bar

Sedmidubsky et al, JSSC 2012





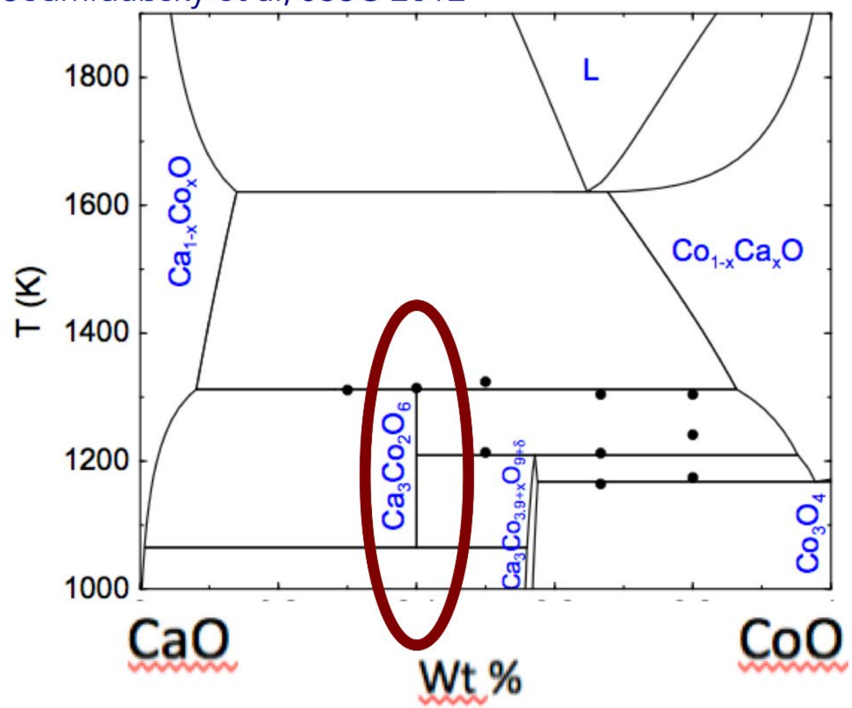
Blueprint question



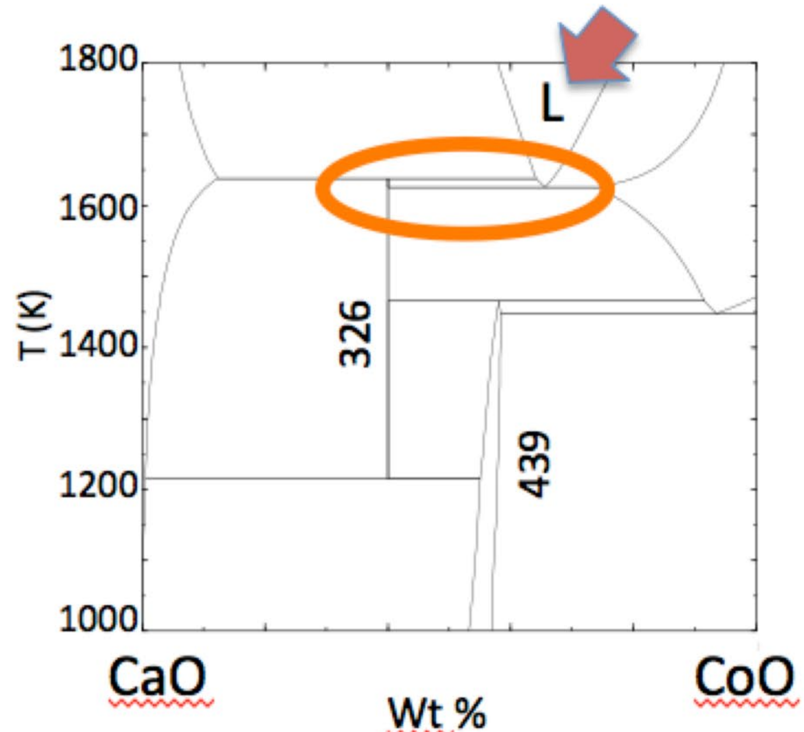
Typical crystal growth knobs:
temperature & composition

pO_2 = 1 bar

Sedmidubsky et al, JSSC 2012

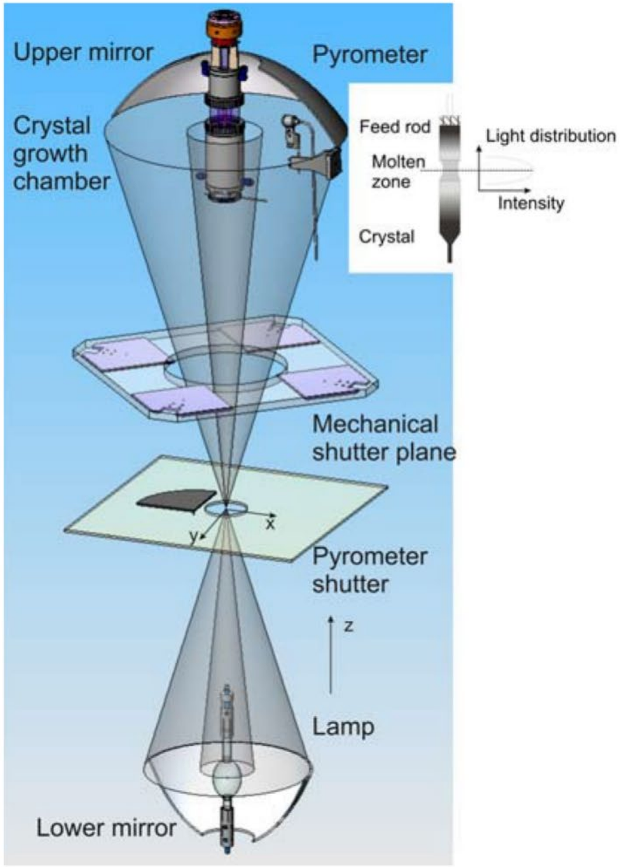


pO_2 = 100 bar



Blueprint question

HP Image Furnace at Argonne National Laboratory



D. Souptel et al. J. Cryst. Growth 300, 538 (2007)