Balloons and Gas Laws

Thomas L. Morton
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Introduction

What will happen to our balloon?

- It will rise
- It will expand while rising
- It will pop, and fall back to earth
- We will talk about the physics of each of these steps.
Topics of Discussion

- How do gases behave?
- Why does a helium balloon rise?
  - What is helium?
- Why does the balloon expand?
- How much can it lift?
- How fast does it go up?
- How far does it go up?
How do gases behave?

- Boyle’s Law – $PV = \text{const}$
- Charles’ Law – $V = \text{const} \times T$
- Avogadro’s Law – Equal volumes at the same temperature and pressure have the same number of molecules. $V = n \ V_{\text{standard}}$
Boyle’s Law

For a given mass, at constant temperature, the pressure times the volume is a constant.

\[ p \ V = C \]
Charles and Gay-Lussac’s Law

For a given mass, at constant pressure, the volume is directly proportional to the temperature:

\[ V = CT \]
What is the Temperature?

Volume doesn’t go to zero at 0° Celsius
Volume does go to zero at -273° Celsius
-273 is defined as Absolute Zero
We use a Temperature scale called Kelvin

º Celsius + 273 = º Kelvin
How do gases behave?

- Boyle’s Law – $PV = \text{const}$
- Charles’ Law – $V = \text{const} \times T$
- Avogadro’s Law – $V = n V_{\text{standard}}$
- Net result – $PV / nT = R$
- $R$ is the gas constant
  - $R = 8.314 \text{ J} / \text{K mol}$
  - $R = 1.987 \text{ cal} / \text{K mol}$
  - $R = .08205 \text{ liter atm} / \text{K mol}$
What is $n$?

In a typical liter of air, there are about $2.7 \times 10^{22}$ molecules.

Scientists use a different counting scale. A gram equivalent of a chemical is called a mole.

$1 \text{ mole} = 6.02 \times 10^{23} \text{ molecules/atoms}$
## The Periodic Table of Elements

### Metals

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### Non-Metals

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<th>Atomic Weight</th>
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<tbody>
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<td>6</td>
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</table>

**Key**

- Solid at room temperature
- Liquid at room temperature
- Gas at room temperature
- Radioactive
- Artificially Made

*The atomic weights listed on this Table of Elements have been rounded to the nearest whole number. As a result, this chart actually displays the *mass number* of a specific isotope for each element. An element's complete, unrounded atomic weight can be found on the JPL Elemental web site: [http://education.jpl.nasa.gov](http://education.jpl.nasa.gov)
Ideal Gas Law

Finally, we have $PV = nRT$

- $P$ in atmospheres
- $V$ in liters
- $n$ in moles
- $T$ in kelvins
- $R = 0.08205$ liter atm / K mol

Valid for moderate temperatures and pressures.

OK for conditions we will see
Why do Helium balloons float?

- Why do boats float?
Why do Helium balloons float?

- Helium balloons “float” in a sea of air.
- Helium weighs less than air.
- Displaces more dense air where balloon is.

Air is 78% Nitrogen, 21% Oxygen, and 1% Argon.

Molecular weight of air is
\[0.78 \times 28 + 0.21 \times 32 + 0.01 \times 40 = 28.96 \text{ g/mol}\]

“Molecular” weight of Helium is 4 g/mol.
Let’s use the ideal gas law

Suppose I have a balloon one foot in diameter
Volume = \( 4\pi r^3/3 = 4\pi (15.24 \text{ cm})^3 / 3 = 14,800\text{ cm}^3 = 14.8 \text{ liters} \).

Weight of that air is:
\[ 14.8/(0.08205*298)*28.96 = 17.5 \text{ gm} \]

Weight of helium is:
\[ 14.8/(0.08205*298)*4 = 2.4 \text{ gm} \]

Lift is 17.5 – 2.4 = 15.1 gm.

Rises if balloon weight is less than 15.1 gm
What is the relevance to balloons?

- Tube demonstration
- Measure pressure in different sized balloons
- Recover balloon from freezer
- Lift equation is a little different
  - Use $P_{\text{internal}}$ for the weight of balloon and Helium
  - Lift is a little less than previous slide
What happens as balloon rises?

- Pressure drops
- Temperature drops, then stays steady
- Consider balloon from a couple slides ago, at 10,000 feet high
  - $P = 700$ mBar = 0.69 atmospheres
  - $T = 0^\circ$ C = 273 kelvins
  - $n = 0.61$ moles
  - $V = nRT / P = 19.6$ liters
  - $R = 3\sqrt{3*V/(4\pi)} = 16.7$ cm > 15.2 cm
What happens as balloon rises? (2)

§ Consider the same balloon, now at 50,000 feet
  u $P = 120 \text{ mBar} = 0.12 \text{ atmospheres}$
  u $T = -60^\circ \text{ C} = 213 \text{ kelvins}$
  u $n = 0.61 \text{ moles}$
  u $V = nRT / P = 88.2 \text{ liters}$
  u $R = \sqrt[3]{\frac{3V}{4\pi}} = 27.6 \text{ cm} \approx 2 \times 15.2 \text{ cm}$
What happens as balloon rises? (3)

Consider the same balloon, now at 100,000 feet

- $P = 10 \text{ mBar} = 0.01 \text{ atmospheres}$
- $T = -50^\circ \text{ C} = 223 \text{ kelvins}$
- $n = 0.61 \text{ moles}$
- $V = nRT / P = 1160 \text{ liters}$
- $R = \frac{3\sqrt{3*V/(4\pi)}}{4} = 65.1 \text{ cm} \approx 4 \times 15.2 \text{ cm}$
- Balloon stretched to 18 x original surface area
- Balloon thickness starts at 0.28 mm, goes to 0.015 mm
Activities

- Measure balloon size, lift, and rise rate:
  - Use string to measure radii.
  - Use scale to measure weight of balloon, and lift.
  - Use stopwatch to measure time to rise from floor to ceiling.
- Use vacuum tank to measure balloon size as a function of pressure.