# Determining Avogadro's number

A Level

On a summer day in 1772, three friends, Benjamin Franklin, John Pringle, and William Brownrigg, went to Derwent Water to see the effect of oil on stilling the waves. However, they were not aware of the fact that what they did on that day could be used to estimate not only the size of the molecules but also what we know today as Avogadro's number.

They had about a teaspoonful of olive oil with them (about $2\,\mathrm{cm}^3$). When they threw the oil into the lake, they estimated that the oil had spread to cover nearly half an acre (about $2000\,\mathrm{m}^2$).

## Part A Thickness of oil

Estimate the thickness of the oil on the lake in $\mathrm{cm}$. Give your answer to 1 significant figure.

## Part B Oleic acid moles

Olive oil consists mostly of oleic acid, of which the molecular weight (or molar mass) is $300$. The density of oil is approximately $1\,\mathrm{g\,cm^{-3}}$. Calculate how many moles of oleic acid there are in the $2\,\mathrm{cm}^3$ olive oil.

## Part C Volume of oleic acid

Calculate the volume of $1\,\mathrm{mol}$ of oleic acid in $\mathrm{cm}^3$.

## Part D Molecular volume

Based upon Benjamin Franklin's experiment, and assuming that the oil forms a monolayer on the lake, calculate the volume of one oleic acid molecule, assuming that it takes a spherical shape. Give your answer in $\mathrm{cm}^3$, to 1 significant figure. (The volume of a sphere of radius $r$ is equal to $4r^3$.)

## Part E Avogadro's number

Estimate Avogadro's number. Give your answer to 1 significant figure.

Used with permission from the Molecular Biology and Biochemistry skills module (BIO0008C), University of York, 2014-15, Worksheet 3, Question 1

# Fireworks!

A Level

Alongside being used in weaponry, gunpowder is also the most important component of fireworks.

It is a mixture of an oxidizing agent, $KNO_3$ and fuel, $C$ and $S$. The most effective ratio of potassium nitrate to carbon to sulfur is $75 : 15 : 10$ by mass (not the stoichiometric ratio for the reaction below).

The reaction between these components forms a mixture of products, the most important being the gaseous ones, $N_2$ and $CO_2$. Assume these can be treated as ideal gases. One simplified form of the reaction can be written as:

$$10\,KNO_3 + 8\,C + 3\,S \longrightarrow 2\,K_2CO_3 + 3\,K_2SO_4 + 6\,CO_2 + 5\,N_2$$

## Part A Limiting reagent

Assuming this is the only reaction that takes place, what is the limiting reagent in gunpowder?

- $C$
- $S$
- $KNO_3$

## Part B Pressure reached

This reaction can heat up to temperatures as high as $1000\,^\circ C$. How high would the pressure in a firework container (cylinder of diameter $d = 7.0\,cm$ and height $h = 50\,cm$) with $100\,g$ of gunpowder become, if it did not explode?

# Elementary Steps

A Level

An **elementary step** of a reaction mechanism is a step that is unimolecular (involving a single atom, molecule or ion of a substance as the reagent), or a step that only involves a single collision between all the species listed as its reagents. In general, reactions can proceed by several elementary steps occurring in succession, or by a more complicated network of elementary steps. Such a network may feature both the forward and reverse reactions of the same step, in some cases, or side reactions that may or may not produce the main products, which complicates the kinetic behaviour of the overall reaction.

The rate equation for an elementary step can be written down without any additional knowledge, as the order of reactants is simply equal to the stoichiometric coefficient in the equation. This means, in particular, that we cannot simply multiply an elementary step arbitrarily. While this would leave the equation balanced, it would represent a different elementary step! We also **cannot** cancel species that appear on both sides of the equation.

## Part A Two elementary steps

Consider the elementary steps $\mathrm{A} \longrightarrow \mathrm{B}$ and $2\,\mathrm{A} \longrightarrow \mathrm{A} + \mathrm{B}$ respectively. Which of the following statements are correct?

- [ ] The equations of the elementary steps are both balanced.
- [ ] The two elementary steps are equivalent.
- [ ] The elementary step $\mathrm{A} \longrightarrow \mathrm{B}$ is unimolecular.
- [ ] The two elementary steps would have the same rate law.

## Part B Rate-determining step

It is common to want to simplify the kinetics of multi-step reactions. Sometimes, it is possible to identify a "rate-determining step", and the rate of the overall reaction can be considered to equal the rate of the rate-determining step.

If the first step in the reaction sequence $\mathrm{A} + \mathrm{B} \longrightarrow \mathrm{C} \longrightarrow \mathrm{D}$ can be considered rate-determining under a certain set of conditions, what rate law would you expect to describe the rate of the overall reaction? Use $r$ to denote the rate, $k$ for the rate constant, and lower-case letters to denote the concentrations of the species (e.g. $[\mathrm{A}] = a$).

The following symbols may be useful: `a, b, c, d, k, r`

## Part C Relative rates

Continuing with the previous set-up with the first step in the reaction sequence $\mathrm{A} + \mathrm{B} \longrightarrow \mathrm{C} \longrightarrow \mathrm{D}$ considered rate-determining, how would you expect the rate of the first step, $r_1$, to compare to the rate of the second step, $r_2$?

The following symbols may be useful: `r_1, r_2`

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Isaac Physics. You work it out.



# Palladium(II) salts

A Level

C C C

Palladium(II) salts can form square planar complexes. Successive addition of ammonia and hydrogen chloride to an aqueous palladium(II) salt produces, under different conditions, three compounds with empirical formula $PdN_2H_6Cl_2$. Two of these, **A** and **B**, are neutral complexes, with $M_r = 211$. **A** has a dipole moment whereas **B** has none. The third compound, **C**, is ionic with $M_r = 422$ and contains palladium in both its cation and anion.

## Part A Compounds A and B

What is the formula of compounds **A** and **B**? Give your answer starting with the metal ion followed by any ligands.

## Part B A and B isomerism

What kind of isomerism is present between compounds **A** and **B**?

## Part C Compound C cation

Give the formula and charge of cation of compound **C** in the format $[\mathrm{Pd}\cdots]^{n+}$.

## Part D Compound C anion

Give the formula and charge of anion of compound **C** in the format $[\mathrm{Pd}\cdots]^{n-}$.

Adapted with permission from UCLES A-Level Chemistry June 1993, Paper 2, Question 1.