Chemistry 201

Atomic mass
Avagadro's number

NC State University

The mass of a proton

The mass of a proton is:

$$1.6726231 \times 10^{-27} \text{ kg}$$

or

$$1.6726231 \times 10^{-24} \text{ grams}$$

We know this value accurately because of mass spectrometry. The number cited here has eight significant figures. We do not usually need this precision, so we often write the value as

$$1.67 \times 10^{-24} \text{ grams}$$

to three significant figures.

Significant figures

The number of significant figures is equal to the number of digits in a measured or calculated value that contribute to its precision. Precision refers to the ability to reproducibly measure or calculate a value.
If we use three significant figures, it suggests that we can reproducibly measure the value to within about 1 part in 100 or with an accuracy of 1%. This is the most common number of significant figures and this will be the default in this course (unless otherwise specified).

Example

The mass of the electron is reported to be:

$$9.1093819 \times 10^{-31}\ \text{kg}$$

Write this number to three significant figures.

Example

The mass of the electron is reported to be:

$$9.1093819 \times 10^{-31} \text{ kg}$$

Write this number to three significant figures.

Solution: The specified value should be as close as possible to the true value so we should round-off the last digit. In this case we round up to obtain

$$9.11 \times 10^{-31} \text{ kg}$$

Example

The mass of a neutron is approximately equal to sum of the masses of an electron and a proton. Give the neutron mass to three significant figures.

Example

The mass of a neutron is approximately equal to sum of the masses of an electron and a proton. Give the neutron mass to three significant figures.

Solution: Start with the accurate values:

$$1.6726231 \times 10^{-27} \text{ kg}$$

$$9.1093819 \times 10^{-31} \text{ kg}$$

Example

The mass of a neutron is approximately equal to sum of the masses of an electron and a proton. Give the neutron mass to three significant figures.

Solution: Start with the accurate values:

$$1.6726231 \times 10^{-27} \text{ kg}$$

$$9.1093819 \times 10^{-31} \text{ kg}$$

Add them together

$$1.6735340 \times 10^{-27} \text{ kg}$$

Example

The mass of a neutron is approximately equal to sum of the masses of an electron and a proton. Give the neutron mass to three significant figures.

Solution: Start with the accurate values:

$$1.6726231 \times 10^{-27} \text{ kg}$$

$$9.1093819 \times 10^{-31} \text{ kg}$$

Add them together

$$1.6735340 \times 10^{-27} \text{ kg}$$

Round of to give

$$1.67 \times 10^{-27} \text{ kg}$$

Example

The actual value of the neutron mass is:

$$1.6749286 \times 10^{-27} \text{ kg}$$

Calculate the difference between the value you obtained by summing the proton and electron masses. How many significant figures are possible in your answer?

Example

The actual value of the neutron mass is:

$$1.6749286 \times 10^{-27} \text{ kg}$$

Calculate the difference between the value you obtained by summing the proton and electron masses. How many significant figures are possible in your answer?

Solution:

Neutron	$1.6749286 \times 10^{-27}$ kg
Proton + electron	$1.6735340 \times 10^{-27}$ kg
Difference	1.3946×10^{-30} kg

There are 5 significant figures in the answer.

Conversion factors for atomic mass

The sum of the mass of a proton and an electron is the mass of a hydrogen atom.

Question: how many hydrogen atoms are there in a gram of H atoms (to 3 significant figures)?

Conversion factors for atomic mass

The sum of the mass of a proton and an electron is the mass of a hydrogen atom.

Question: how many hydrogen atoms are there in a gram of H atoms (to 3 significant figures)?

Answer: The calculated value actually has units

$$1.6735340 \times 10^{-27}\ \text{kg/atom}$$

Or

$$1.6735340 \times 10^{-24}\ \text{grams/atom}$$

Therefore, we can invert it to find,

$$5.97(5) \times 10^{23}\ \text{atoms/gram}$$

Atomic mass unit

When we consider all of the atoms in the periodic table, the average mass of a nucleon is considered to be:

$$1.6605388 \times 10^{-24} \text{ grams/nucleon}$$

We call this the atomic mass unit. We can use this value to convert atomic masses to grams or vice versa. We write the conversion as,

$$1.6605388 \times 10^{-24} \text{ grams/amu}$$

To employ this value we calculate the atomic mass of an atom or molecule and then we can calculate the weight in grams using this formula.

Avagadro's number

If we invert average atomic mass

$$\frac{1}{1.6605388 \times 10^{-24} \text{ grams/amu}}$$

We obtained the number of particles with a given amu per gram. This number is called Avagradro's number and is given the symbol N_A.

$$N_A = 6.022141 \times 10^{23} \text{ amu/gram}$$

This number gives the number of particles for which an atomic mass has the the same value in grams.

1 H atom = 1 amu $\quad$ N_A H atoms = 1 gram

1 C atom = 12 amu $\quad$ N_A C atoms = 12 grams

Example

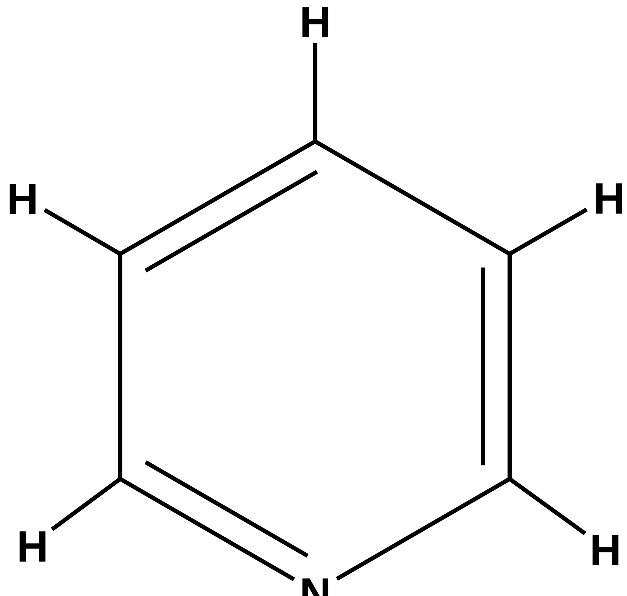
How much does a molecule of pyridine weigh?

(Ummm… all right, what is its mass?)

Example

How much does a molecule of pyridine weigh?

Solution: First, we find the chemical formula for pyridine. C_5H_5N



Example

How much does a molecule of pyridine weigh?

Solution: Second, we look up the atomic masses in the periodic table.

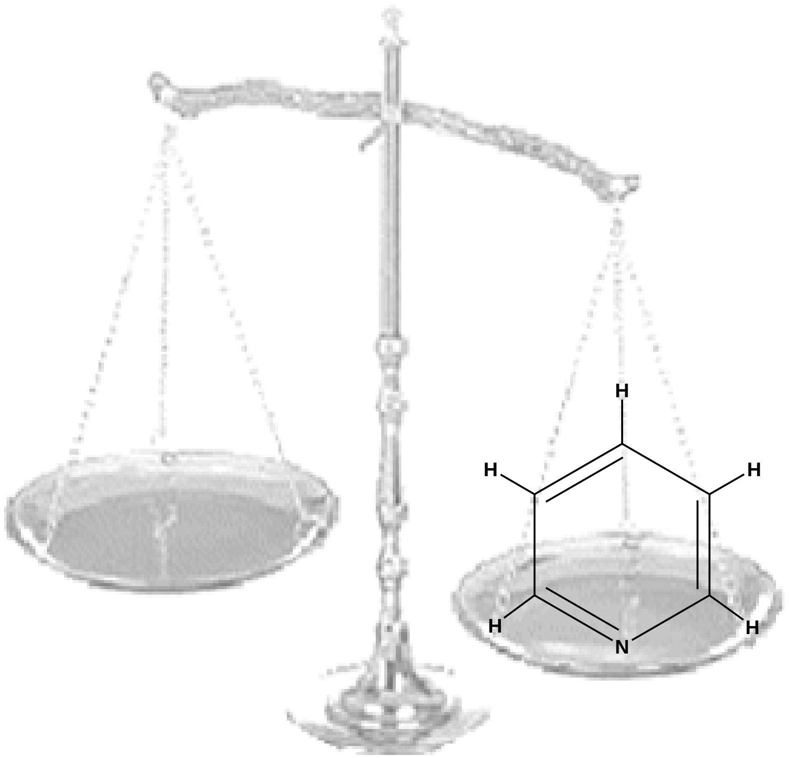
atomic mass = 5(12) + 5 + 14 = 79 amu

Third, we use the conversion factor to calculate the mass in grams

$(79 \text{ amu}) \times (1.66 \times 10^{-24} \text{ grams/amu}) = 1.31 \times 10^{-23} \text{ grams}$

Avogadro’s number

It is a bit difficult to weigh out 10^{-23} grams.



Avogadro's number

Instead, let's ask how many molecules it takes to convert the atomic mass to its value in grams.

For example, using the grams/amu conversion, let's calculate how many hydrogen atoms have the mass of 1 gram.

Avogadro's number

Instead, let's ask how many molecules it takes to convert the atomic mass to its value in grams.

For example, using the grams/amu conversion, let's calculate how many hydrogen atoms have the mass of 1 gram.

Answer: since hydrogen weighs 1 amu, its mass is

$$1.6605388 \times 10^{-24} \text{ grams/atom}$$

We can invert this value to find the number of atoms per gram.

$$6.0221417 \times 10^{23} \text{ atoms/gram}$$

The mole

Since this number converts from atoms to gram for hydrogen, we can see that it can be used to give the number of atoms for any formula weight (i.e. molecular weight of a compound given in grams). For example, pyridine has a formula weight of 79 grams. Therefore, There are 6.0221417×10^{23} molecules in 79 grams of pyridine. Because of the importance of this number of atoms or molecules we give the name, mole.

$$1 \text{ mole} = 6.0221417 \times 10^{23} \text{ molecules}$$

or to 3 significant figures.

$$1 \text{ mole} = 6.02 \times 10^{23} \text{ molecules}$$

Avogadro's number as a conversion factor

Given the definition,

$$1 \text{ mole} = 6.02 \times 10^{23} \text{ molecules}$$

We can see that Avogadro's number converts from molecules to moles.

$$6.02 \times 10^{23} \text{ molecules/mole}$$

Atomic weight and molar mass

The atomic weight is the numerical value tabulated for the mass of each atom in the periodic table in atomic units. The use of the word "weight" is not precise here since weight in physics represents a force ($w = mg$). However, the name atomic weight is so ingrained that we will not attempt to change it. We use the periodic table to calculate the molar mass as follows: for H_2SO_4 we find the atomic weights, H = 1, S = 32 and O = 16.

Molar mass = 2(1 g/mol) + 32 g/mol + 4(16 g/mol)
= 98 g/mol