



# Concepts and definitions

- Atomic number - number of protons in the nucleus ( $Z$ )
- Isotopes - atoms with same  $Z$  but different number of neutrons ( $N$ )
- Mass number:  $A = Z + N$
- Isobars: Atoms with same  $A$ , but different  $Z$  (and  $N$ )
  - e.g.  $^{81}\text{Zn}$ ,  $^{81}\text{Ga}$ ,  $^{81}\text{Ge}$
- (Isotones - atoms with same  $N$  but different  $Z$ )
- Nuclide: atom type characterized by a specific  $N$  and  $Z$
- Nucleon, proton or neutron
- Isomer, atoms a specific nuclide, in a particularly long-lived excited state, different from the ground state



# Isotopes

	$^{17}\text{F}$	$^{18}\text{F}$	$^{19}\text{F}$	$^{20}\text{F}$	$^{21}\text{F}$	$^{22}\text{F}$	$^{23}\text{F}$	$^{24}\text{F}$
	64.5s	1.82h	stabil	11.0s	4.4 s	4.2 s	2.3 s	0.3 s
	$\beta^+$	$\beta^+$	100%	$\beta^-$	$\beta^-$	$\beta^-$	$\beta^-$	$\beta^-$

- Fluorine isotopes exist on the following masses; 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, in total 12.
  - ▶  $^{19}\text{F}$  is the only stable F isotope
  - ▶  $^{18}\text{F}$  and  $^{17}\text{F}$  are  $\beta^+$ -active
  - ▶ All the remaining are  $\beta^-$ -active
- $^{16}\text{F}$  is **unbound**, i.e. it does not exist. It is not possible. This position is called the “proton drip-line”. All lighter F-isotopes are also unbound
- $^{28}\text{F}$  is unbound, so is  $^{30}\text{F}$  and all heavier F-isotopes.  $^{28}\text{F}$  and  $^{30}\text{F}$  are just above the “neutron drip-line”



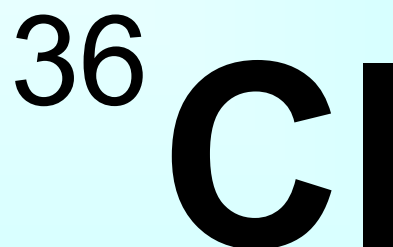
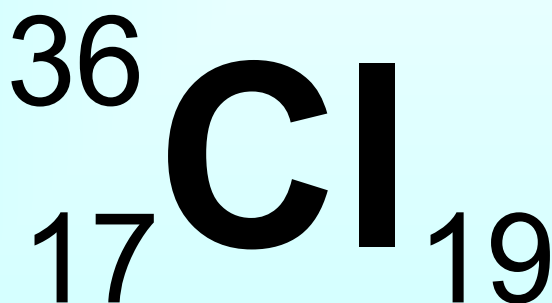
## Notation



- A - mass number
- Z - proton number
- N - neutron number
- X - chemical element signature

Example:

Or just:



Do not use: ~~Cl-36~~ or ~~cl<sup>36</sup>~~



# Energies and units

- 1 eV (electron-volt) =  $1.6 \cdot 10^{-19}$  J
- 1 keV =  $10^3$  eV
- 1 MeV =  $10^6$  eV
- 1 GeV =  $10^9$  eV
- 1 TeV =  $10^{12}$  eV
- ~eV - chemical binding
- ~keV - binding energies for inner shell electrons in heavy elements
- 511 keV electron rest mass
- ~MeV - energies in simple nuclear processes
- ~200 MeV - fission energies
- 0.94 GeV - nucleon rest mass (proton or neutron)



# Disintegration and time

- **Assumptions:**
- 1. We have a number  $N$  radioactive atoms of the same nuclide
- 2. Their probability of decay is independent of their past history
- 3. They decay without interactions with the surroundings
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- What is the disintegration rate as a function of time ?



# The decay law

Consider a time-interval  $\Delta t$ . During this time a number of atoms  $-\Delta N$  (positive number) will disintegrate. We consider  $\Delta t$  so small that the condition  $-\Delta N \ll N$  is fulfilled. Then we have:

$$-\Delta N \propto \Delta t \quad \text{and}$$

$$-\Delta N \propto N \quad \text{(assumption 3)}$$

$$\text{Hence: } -\Delta N = \lambda N \Delta t$$

$$\text{or: } -dN = \lambda N dt \quad \text{i.e. } -dN/N = \lambda dt$$

Integration:

assumption 2

$$\int_{N_0}^N -dN/N = \int_{t=0}^t \lambda dt = \lambda \int_{t=0}^t dt$$

gives  $-\ln(N/N_0) = \lambda t$  or

$$N = N_0 e^{-\lambda t}$$

Like a 1st order chemical reaction



# Disintegration and number of atoms

The constant  $\lambda$  is the decay constant, characteristic of each nuclide, and expresses the **probability per unit time that one atom will decay**. Hence the product

$$\lambda N \equiv D$$

expresses the number of disintegrations per unit time, or the disintegration-rate of that particular nuclide. As for a 1st order chemical reaction, we have:

$$\lambda = \ln(2)/T_{1/2}$$

It is also easily seen that for a single decay, one has:

$$D = D_0 e^{-\lambda t}$$

where  $D_0$  is the disintegration rate at  $t=0$



# Unit

- Unit for disintegration-rate (decay-rate): 1 becquerel = 1 Bq
- 1 Bq = 1 disintegration per second
- 1 kBq =  $10^3$  Bq
- 1 MBq =  $10^6$  Bq
- 1 GBq =  $10^9$  Bq
- 1 TBq =  $10^{12}$  Bq
- 1 PBq =  $10^{15}$  Bq
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- Disintegration rate should be specified to a particular nuclide, or to total disintegration rate





# Disintegration rate and mass

The total amount of Pu in the world was in 2009 approximately 2100 tons.

Calculate the disintegration rate, assuming that all Pu is  $^{239}\text{Pu}$ , with half-life of 24 000 years.

(World production of Pu: ~70 tons per year, a small fraction of it is used in MOX fuel)

1) Find the number of moles:

$$n = 2.1 \cdot 10^9 / 239 = 8.8 \cdot 10^6$$

2) Number of atoms:

$$N = N_A \cdot n = 6.022 \cdot 10^{23} \cdot 8.8 \cdot 10^6 \\ = 5.3 \cdot 10^{30}$$

3)  $D = \lambda N = N(\ln 2) / T_{1/2} =$

$$5.3 \cdot 10^{30} \cdot (\ln 2) / (24000 \text{ (y)} \cdot 3.16 \cdot 10^7 \text{ (s/y)}) =$$

$$\mathbf{4.8 \cdot 10^{18} \text{ Bq}}$$



## Environmental aspects

The Kara Sea is about 2000 km long, 500 km wide and 200 m deep.

Total volume:  $V = 200 \cdot 500\,000 \cdot 2000\,000$   
 $= 2 \cdot 10^{14} \text{ m}^3$ .

Assume: Someone gets holds on all the world's Pu, dissolves it in nitric acid and pours it into the Kara Sea, where it is not sedimented.

Activity concentration;  $4.8 \cdot 10^{18} \text{ Bq} / 2 \cdot 10^{14} \text{ m}^3$   
 $= 24000 \text{ Bq/m}^3 = 24 \text{ Bq/l}$



## Decay law, example

- A source of  $^{99m}\text{Tc}$  (6.0 h) has a disintegration rate of  $1.0 \cdot 10^7$  Bq. What is the disintegration rate after 3.0 hours ?
- $\lambda = (\ln 2)/T_{1/2} = (\ln 2)/6.0(\text{h}) = 0.116(\text{h}^{-1})$
- $D = D_0 e^{-\lambda t} = 1.0 \cdot 10^7 e^{-0.116 \cdot 3.0} = 7.1 \cdot 10^6$  Bq
- How many atoms  $^{99m}\text{Tc}$  are present now ?
- $N = D/\lambda = DT_{1/2}/(\ln 2) = 7.1 \cdot 10^6 \cdot (6.0 \cdot 3600)/(\ln 2) = 2.2 \cdot 10^{11}$
- What's the number of moles ?
- $2.2 \cdot 10^{11}/6.022 \cdot 10^{23} = 3.7 \cdot 10^{-13}$