SPACED RETRIEVAL / INTERLEAVING

RETRIEVAL PRACTICE

5 minutes

1. **Describe** the nuclear model of the atom.

2. **Explain** why protons in the nucleus repel each other.

3. **Describe** the term ‘strong nuclear force’.

DEMO / WORKED SOLUTIONS

RETRIEVAL SOLUTION

1. **Describe** the nuclear model of the atom.

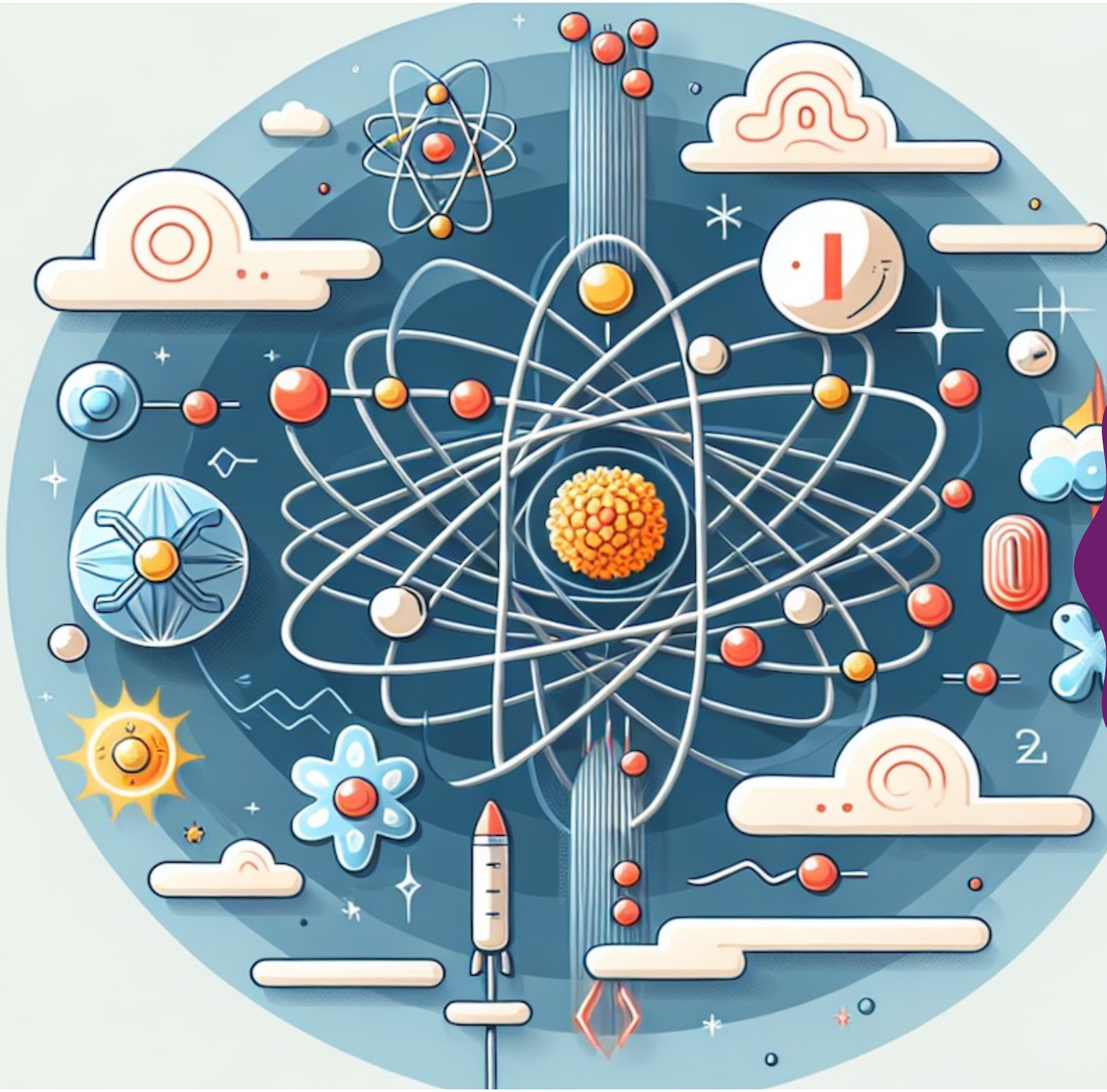
The nuclear model of the atom states that an atom is made up of a central, positively charged, dense nucleus which contains protons and neutrons.

2. **Explain** why protons in the nucleus repel each other.

Protons are positively charged, multiple protons will therefore repel each other due to their like charges – this is the law of electrostatics (like charges repel & unlike charges attract).

3. **Describe** the term 'strong nuclear force'.

One of the four fundamental forces; the SNF acts over small distances in the nucleus to hold the nucleons together against the repulsive electrostatic forces exerted between the protons.



LESSON 2

Stability of the Atom & Spontaneous Decay

LEARNING OBJECTIVES

By the end of this lesson, you should be able to:

- ❑ **Explain** the stability of a nuclide in terms of:
  - the operation of the strong nuclear force over very short distances
  - electrostatic repulsion
  - the relative number of protons and neutrons in the nucleus
- ❑ **Explain** natural radioactive decay in terms of stability.

TASK / ACTIVITY

WHICH IS STABLE? WHY?

Discuss in your table groups

TASK / ACTIVITY

WHICH IS STABLE? WHY?

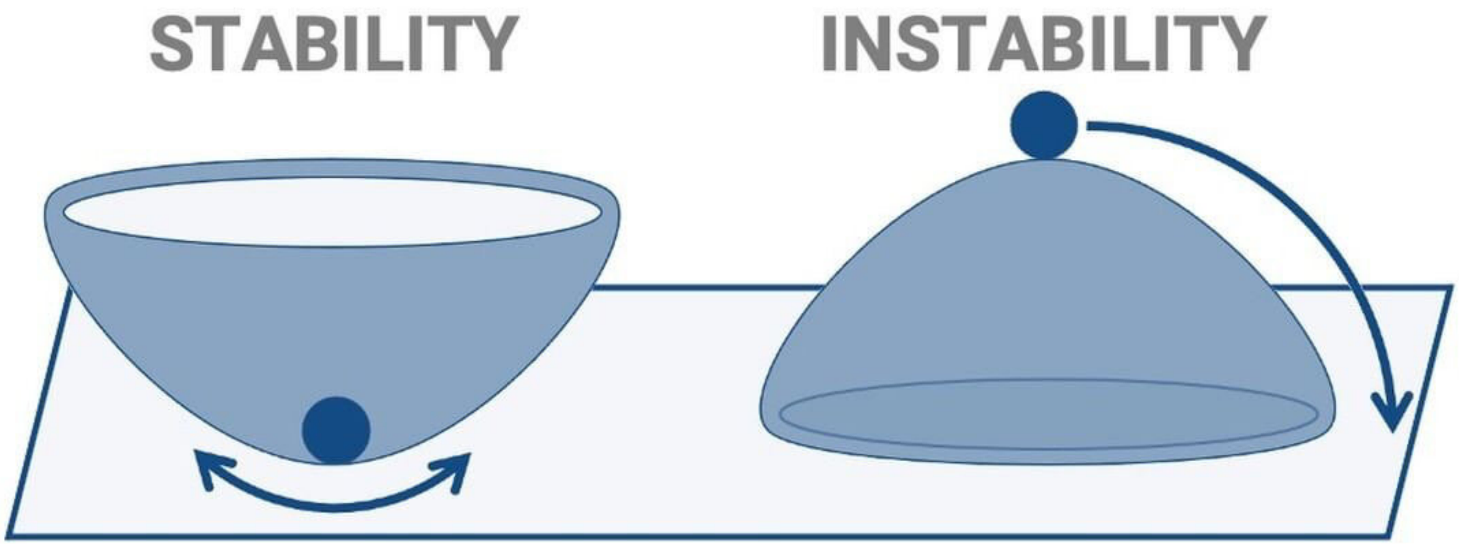
Discuss in your table groups

LESSON CONTENT

STABILITY

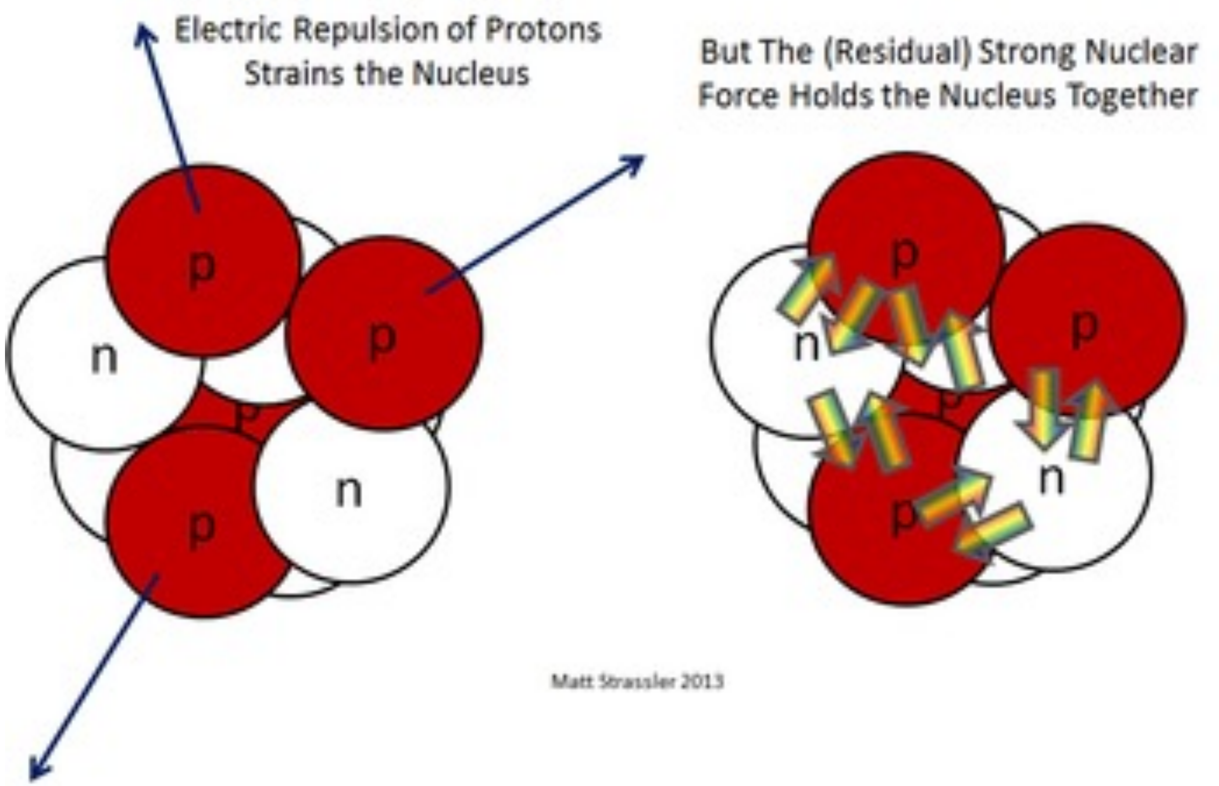
Stability in general is a measure of how likely things are to change in the future.
Some colloquial analogies for stability include:

- Balance
- Strength
- Security
- Steadiness



What ideas from physics do these words bring to mind?

THE TWO TYPES OF FORCES

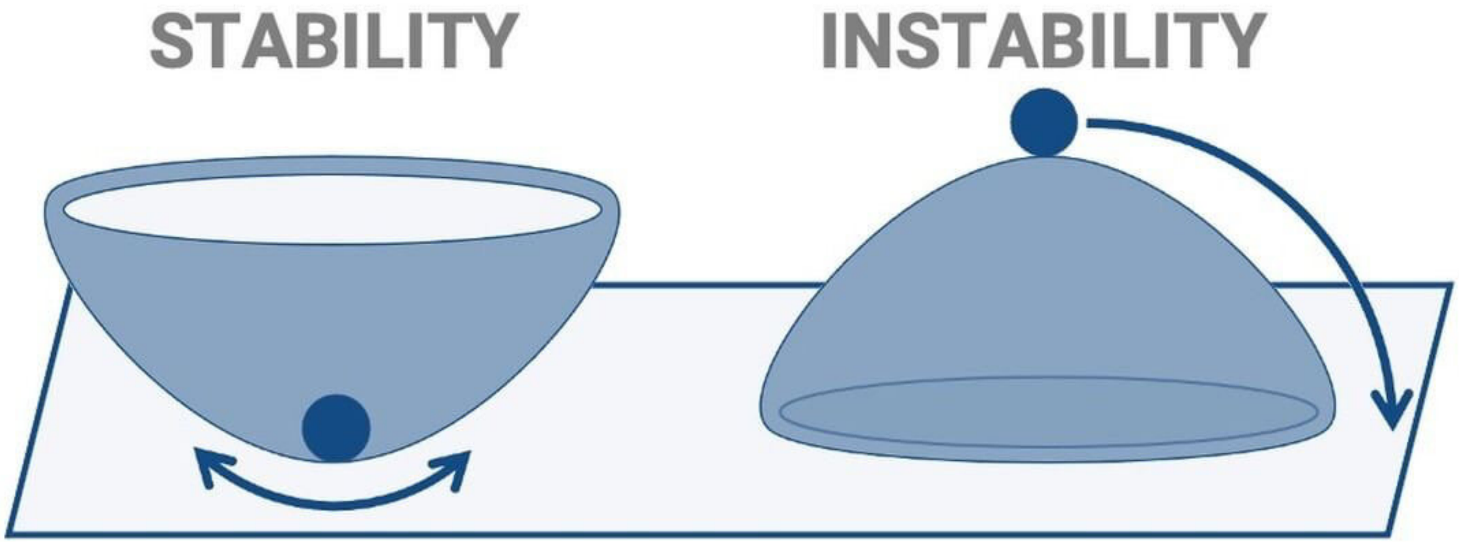


Nuclear Stability is a measure of how these two forces are balanced as well as the overall energy within the nucleus (potential, kinetic etc).

LESSON CONTENT

STABILITY AND ENERGY

A nucleus is stable if it cannot be transformed into another configuration without an input of energy from an external source.



If we take the bowl to resemble our nuclear stability. The stable configuration requires an input of energy for the ball to leave the bow. The upside down bowl does not require an input of energy before the ball rolls down the side of the bowl.

STABILITY AND ENERGY

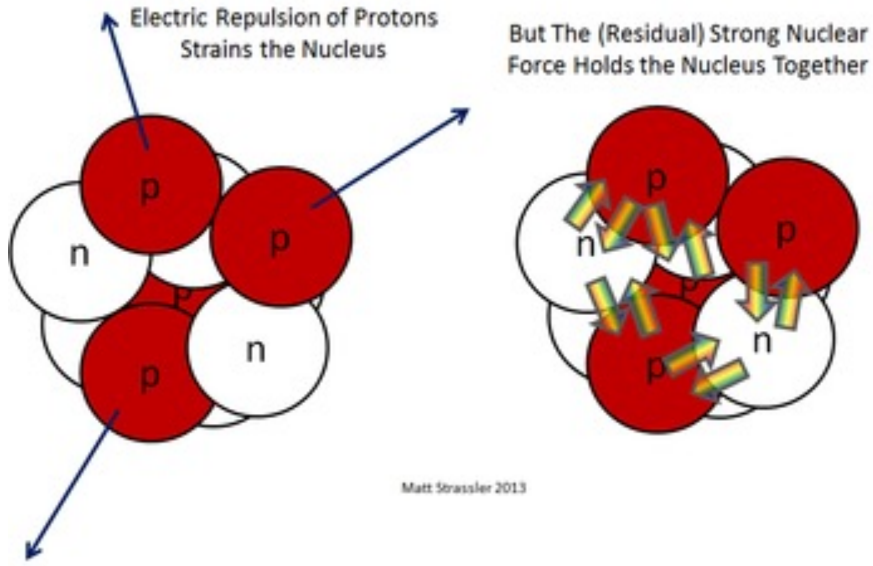
In our nucleus example –

If $F_{strong} > F_{repulsion}$

Then removing a nucleon from the nucleus (e.g a proton) requires an input of energy. The nucleus is relatively stable.

If $F_{strong} < F_{repulsion}$

Then removing a nucleon from the nucleus is much easier. If the repulsive force is strong enough the nucleus will change its composition spontaneously.

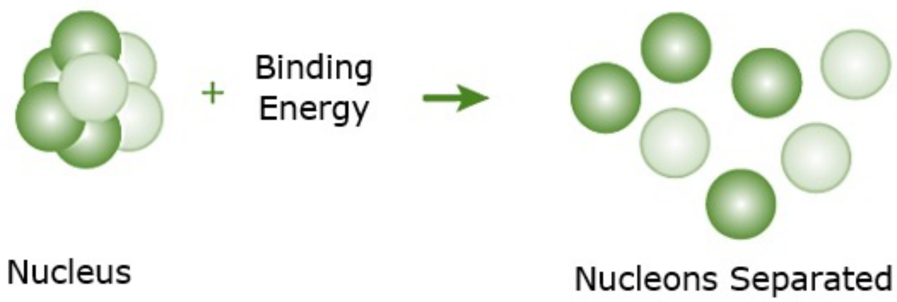


Note: this is just one way a nucleus can be unstable. We will learn there are others too.

STABILITY AND ENERGY

We measure nuclear stability in terms of the Binding Energy of a nucleus.

Binding energy is the energy that **binds** the nucleus together. It is usually a negative value as it represents the energy **required** to disassemble a nucleus (think: activation energy in a chemical reaction).



The higher the binding energy per nucleon, the higher the stability.

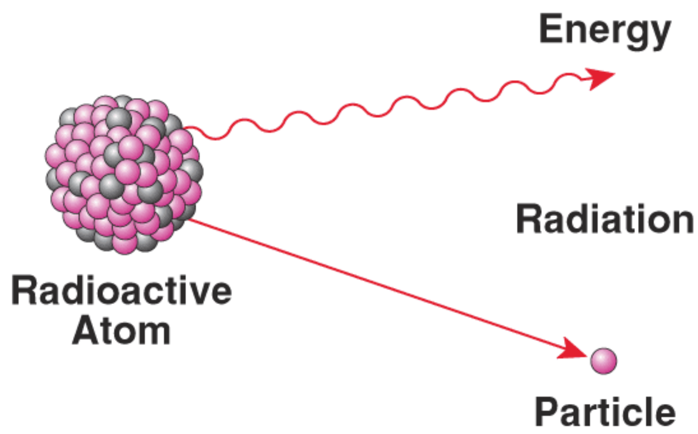
LESSON CONTENT

UNSTABLE PARTICLES AND SPONTANEOUS DECAY

Nuclear decay is a nuclear process wherein one particle transforms from one type to another. This process is **spontaneous** if it occurs **randomly** with **no input energy.**

The more unstable a particle is, the more quickly it will decay.

Unstable nuclei undergo **radioactive decay** and emit one of several forms of **radiation** to achieve a more stable nucleus.



NUCLEAR INSTABILITY

A nucleus will become **unstable** and undergo **spontaneous decay** if it has:

	Excess mass	Unstable ratio	Excess energy
Caused by	Excess protons and neutrons (High surface area to volume ratio)	Excess protons or neutrons (High coulomb repulsion or particle asymmetry)	Nucleus being in an excited state (Not related to binding energy)
Description	An abundance of particles ($Z > 82$) creates a nucleus with a diameter larger than the range of the SNF. Particles closer to the surface are easy to remove.	The ratio of protons to neutrons varies with isotopes. Too many protons or too many neutrons causes instability.	During decay, when a nucleus emits a particle, the daughter nucleus is left in an excited state.
To increase stability	The nucleus must expel mass to reduce its size.	The nucleus must transform either protons (positive charge) into neutrons or vice versa.	Emits energy (similar to electrons jumping to lower energy states).
Type of decay	Alpha decay	Beta decay	Gamma radiation

We'll learn more about types of decay in another lesson.

TASK / ACTIVITY

TASK 1: FILL IN THE BLANKS

Excess Protons AND Neutrons

An excess of protons and neutrons (Z > ___) increases the ___ of the nucleus such that it creates an unstable ___ ratio.

The particles closer to the surface are only weakly held onto by the ___.

The nuclide must undergo radioactive decay to release excess ___ to reduce its ___ becoming more stable.

Excess Protons

An excess of protons in the nucleus increases the ___ acting on the nucleons.

This creates an imbalance between the ___ and the ___ in the nucleus.

The nuclide must undergo radioactive decay to reduce the ___ in the nucleus to reduce the ___, becoming more stable.

Excess Neutrons

An excess of neutrons in the nucleus creates an ___, causing the nucleons to become too ___

This creates an imbalance between the kinetic energy of the particles and the ___ in the nucleus.

The nuclide must undergo radioactive decay to reduce the ratio of ___ in the nucleus to create a stable ratio of nucleons present.

DEMO / WORKED SOLUTIONS

TASK 1: SOLUTION

Excess Protons AND Neutrons

An excess of protons and neutrons (Z > 82) increases the size of the nucleus such that it creates an unstable surface-area to volume ratio.

The particles closer to the surface are only weakly held onto by the strong nuclear force.

The nuclide must undergo radioactive decay to release excess protons and neutrons to reduce its size, becoming more stable.

Excess Protons

An excess of protons in the nucleus increases the electrostatic repulsion acting on the nucleons.

This creates an imbalance between the strong nuclear force and the electrostatic force in the nucleus.

The nuclide must undergo radioactive decay to reduce the number of protons in the nucleus to reduce the Coulomb force, becoming more stable.

Excess Neutrons

An excess of neutrons in the nucleus creates an unstable ratio, causing the nucleons to become too energetic.

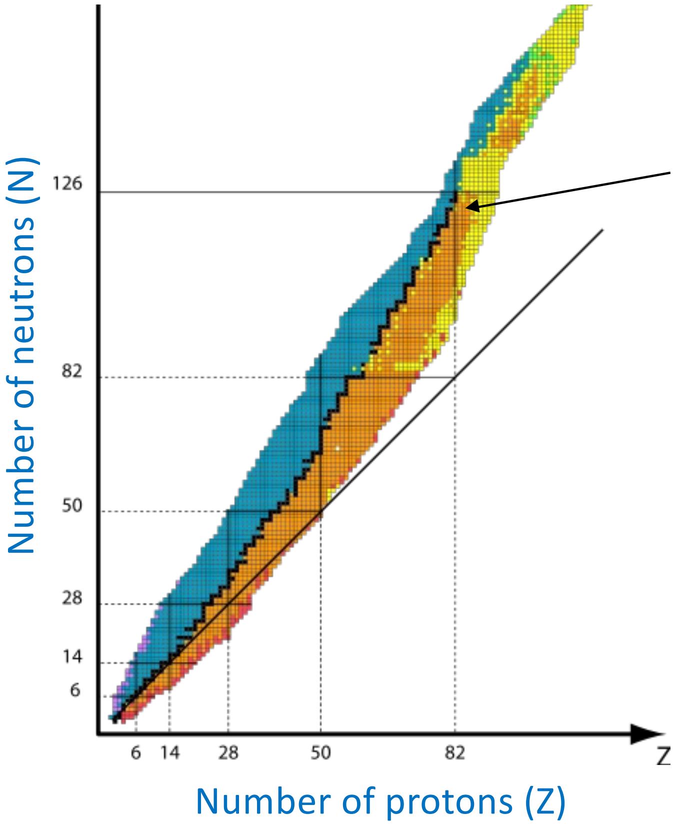
This creates an imbalance between the kinetic energy of the particles and the strong nuclear force in the nucleus.

The nuclide must undergo radioactive decay to reduce the ratio of neutrons to protons in the nucleus to create a stable ratio of nucleons present.

LESSON CONTENT

SEGRE CHART

A **Segre chart** (or table of nuclides), also called an **N vs Z graph**, shows how the **ratio** of neutrons (N) to protons (Z) changes with the number of protons for different **isotopes**.



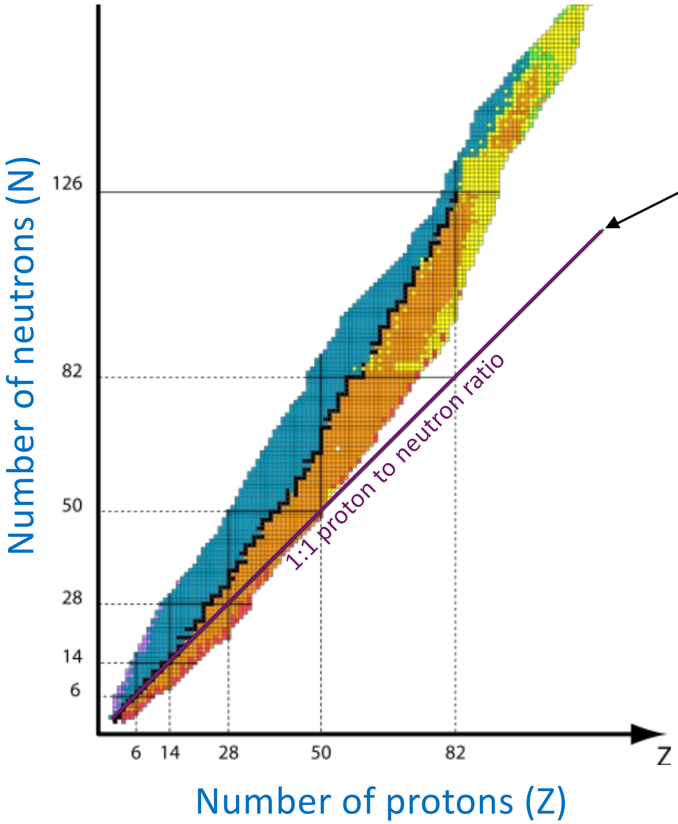
Features of the graph include:

The **stability line** has a slight upward curve because as the neucleus gets bigger, it needs a larger number of neutrons to maintain stability. It stops suddenly at lead (Z = 82).

The stability line shows the **ideal ratio** of neutrons to protons. Isotopes close to the stability line are most stable and won’t undergo spontaneous decay. Away from the line, indicates isotopes that will undergo **spontaneous decay** at some time.

SEGRE CHART

A **Segre chart** (or table of nuclides), also called an **N vs Z graph**, shows how the **ratio** of neutrons (N) to protons (Z) changes with the number of protons for different **isotopes**.



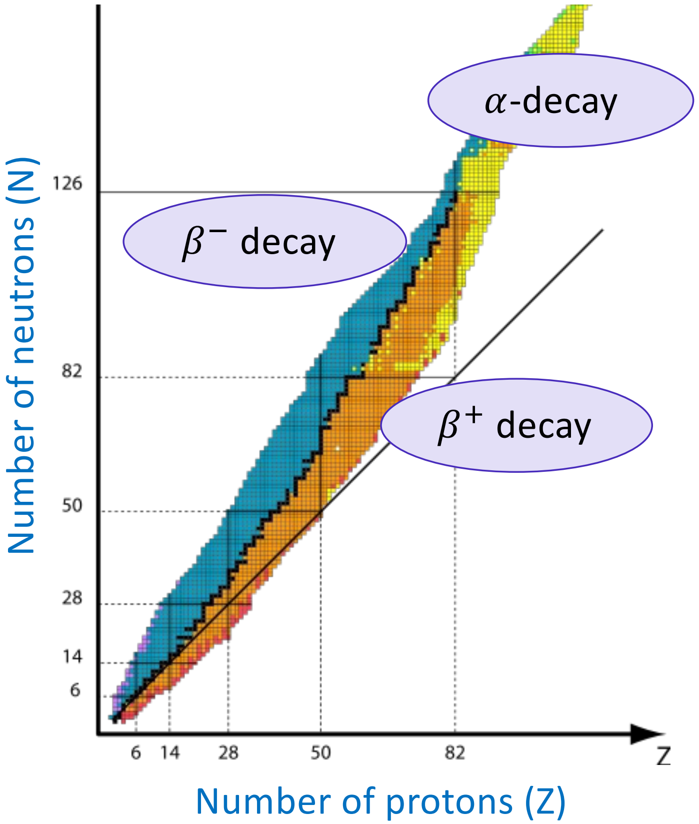
Features of the graph include:

The **1:1 proton to neutron ratio**.

- For smaller atoms, **Z < 10**, the optimal ratio of protons to neutrons is 1:1
- For larger atoms, For **Z > 10**, the optimal ratio increases to **1:1.5**
- This is because as the number of protons in a nucleus increases, the repulsive electrostatic force increases, thus, more neutral particles are needed to balance that force so that SNF can act.

SEGRE CHART

A **Segre chart** (or table of nuclides), also called an **N vs Z graph**, shows how the **ratio** of neutrons (N) to protons (Z) changes with the number of protons for different **isotopes**.



Features of the graph include:

Unstable zones

- Isotopes away from the stability lines are **unstable**. The goal of decay is to stabilise the isotope moving them towards the stability line.
- There are three distinct **zones** on the graph which **indicate the type of decay** the isotope will undergo to stabilise. (more on types of decay in another lesson)

TASK / ACTIVITY

TASK 2: STABILITY

10 minutes

Ruthenium 101 and Ruthenium 102 are stable isotopes, but Ruthenium 103 is not.

1. Present the three isotopes of Ruthenium using atomic notation.

Click to show

2. Explain why Ruthenium 103 is unstable.

Click to show

TASK / ACTIVITY

TASK 2: STABILITY

10 minutes

Ruthenium 101 and Ruthenium 102 are stable isotopes, but Ruthenium 103 is not.

1. Present the three isotopes of Ruthenium using atomic notation.

$$^{101}_{44}\mathrm{Ru},\ ^{102}_{44}\mathrm{Ru},\ ^{103}_{44}\mathrm{Ru}$$

2. Explain why Ruthenium 103 is unstable.

Ruthenium 103 has an additional neutron to Ruthenium 102, a known stable isotope of Ruthenium. For an additional neutron to cause the isotope to be unstable means that the extra neutron added creates an **unstable ratio** of protons to neutrons.

DEMO / WORKED SOLUTIONS

TASK 2: STABILITY

10 minutes

Ruthenium 101 and Ruthenium 102 are stable isotopes, but Ruthenium 103 is not.

1. Present the three isotopes of Ruthenium using atomic notation.

$$ {}^{101}_{44}\mathrm{Ru},\ {}^{102}_{44}\mathrm{Ru},\ {}^{103}_{44}\mathrm{Ru} $$

2. Explain why Ruthenium 103 is unstable.

Ruthenium 103 has an additional neutron to Ruthenium 102, a known stable isotope of Ruthenium. For an additional neutron to cause the isotope to be unstable means that the extra neutron added creates an **unstable ratio** of protons to neutrons.

CHECK FOR UNDERSTANDING

CFU – FACTS AND FIBS SOLUTION

- For each of the statements below about nuclear stability, identify whether it is a fact or a fib.
  If it is a fib, rewrite it so that it becomes a fact.

- A stable nucleus always has equal ratios of protons and neutrons.

Click to show

- At very high atomic numbers (83 or greater), there are no stable isotopes.

Click to show

- Too many protons in the nucleus creates an excess of electrostatic repulsion.

Click to show

- Too many neutrons in the nucleus creates an excess of the strong-nuclear force.

Click to show

DEMO / WORKED SOLUTIONS

CFU – FACTS AND FIBS SOLUTION

- For each of the statements below about nuclear stability, identify whether it is a fact or a fib.
  If it is a fib, rewrite it so that it becomes a fact.

- A stable nucleus always has equal ratios of protons and neutrons.
  - **FIB** – this is only true for $Z \leq 10$
- At very high atomic numbers (83 or greater), there are no stable isotopes.
  - **FACT**
- Too many protons in the nucleus creates an excess of electrostatic repulsion.
  - **FACT**
- Too many neutrons in the nucleus creates an excess of the strong-nuclear force.
  - **FIB** – Too many neutrons creates an unstable ratio, it is impossible for there to be too much SNF

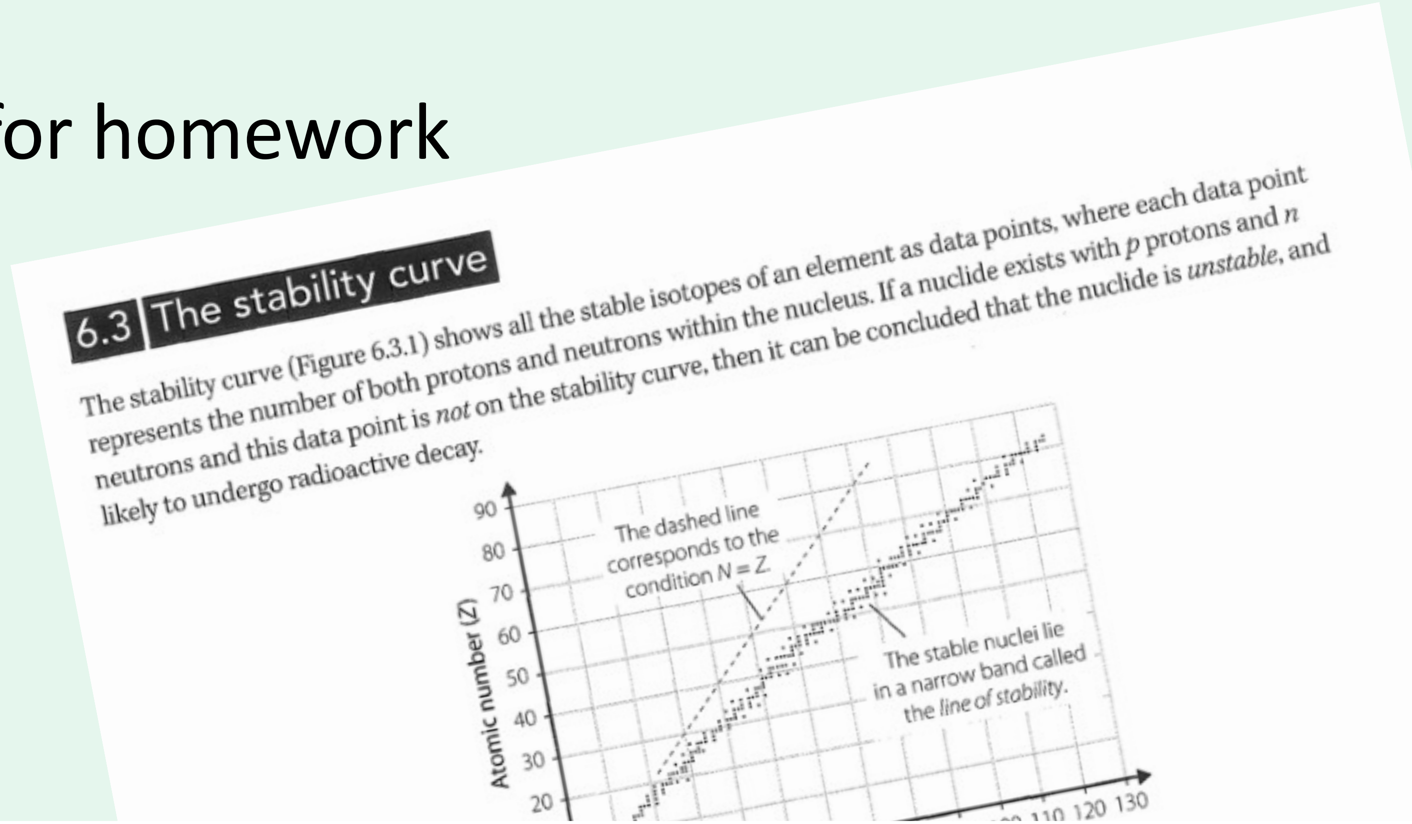
TASK / ACTIVITY

TASK 3: PRACTICE

15 minutes

Access the Worksheet “WS 1.2.2 Stability Curve”

Start now, finish for homework



6.3 The stability curve

The stability curve (Figure 6.3.1) shows all the stable isotopes of an element as data points, where each data point represents the number of both protons and neutrons within the nucleus. If a nuclide exists with *p* protons and *n* neutrons and this data point is *not* on the stability curve, then it can be concluded that the nuclide is *unstable*, and likely to undergo radioactive decay.

LEARNING OBJECTIVES

Can you:

✓ **Explain** the stability of a nuclide in terms of:

- ✓ the operation of the strong nuclear force over very short distances
- ✓ electrostatic repulsion
- ✓ the relative number of protons and neutrons in the nucleus

✓ **Explain** natural radioactive decay in terms of stability.

RECOMMENDED / WATCH

STILL WOBBLY?

1. Watch this:

Nuclear Stability – Band of Stability

https://www.youtube.com/watch?v=_fhBGGbzzw

2. Read Oxford Textbook Chapter 4.2

AFTER CLASS

HOMEWORK

- ❑ Complete the Stability Curve Worksheet

  WS 1.2.2 Stability Curve

- Upload to QLearn