**Source**: ⟦KBPhysicsMasterIndex⟧

# 1 | **Nuclear Physics**

First of all, recall ⟦KBhPHYS201ColoumbsLaw⟧. Given the force between two particles is $\frac{kQ^2}{R^2}$, we could hand-wavily calculate the *work* between two particles if we know how much they travel near/far from each other. Through this, we could show that nuclear forces (through nuclear distance, proton=>electron) are much larger than that of the chemical forces (atom/atom, electron=>electron).

#compilefromnote

Remember: $A_{nucl} = \frac{1}{10^{10}} A_{atom}$

## 1.1 | **Radioactivity**

Radiation is the emition of waves — lights, heat, etc. etc. We call something "radioactive" if it emits ionizing radiation: that it has enough energy to liberate an electron from an atom.

### 1.1.1 | **Geiger Counter**

#inserthowgeigercountersowrk

Because of the fact that Geiger counters require time to discharge, there is a certain rate called "dead time" during which Geiger counters simply sit and do nothing. As such, we have to account for this lossy "deadtime" of Geiger counters by relating the two values with the following equation

$T = \frac{M}{1-(M/L)}$, where $M$ is the measured rate of radiation and $L$ is the "dead time" — the upper limit of the Geiger counter in question.

### 1.1.2 | **Radio Charge Types**

- $\alpha$: positively charged + relatively massive (low $\frac{q}{m}$)
- $\beta$: negatively charged + relatively high charge (high $\frac{q}{m}$)
- $\gamma$: neutral

This could be seen by how these three types of charge curve into a magnetic field.

Figure 1: Different charges in a magnetic field

Why? Apply right hand rule 1.5.

### 1.1.3 | **Creating a ray**
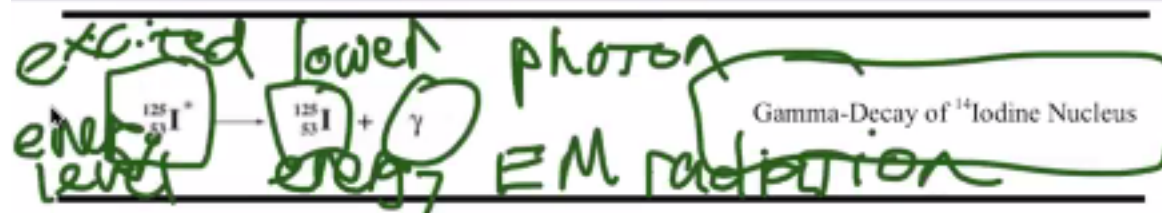
"Split a nucleus, somehow"

**Alpha Decay**:



During alpha decay, a massive nucleolus spits out a Helium-resulting part of itself to get rid of 2 protons and 2 neutrons. So, formally…



$\alpha$ decay:
$$_Z^A N \rightarrow {}_{Z-2}^{A-4}N' + {}_2^4 He$$

**Gamma Decay**

Instead of splitting part of the nucleus, gamma decay spits an electrically excited (so… chemistry, charged, energy level, that stuff) atom into a normal, non-excited atom and also emits a photon.

$\gamma$ *decay:*

$$^A_Z N^* \rightarrow {}^A_Z N + \gamma$$

excited lower photon

energy

level

energy EM radiation

Gamma-Decay of $^{14}$Iodine Nucleus

And now, the most confusing one…

**Beta Decay** There's two types of beta decay: "beta-minus" decay and "beta-plus" decay. When folks talk about just "beta-decay", they are talking about beta-minus decay.

An element decays from the parent element into a different nucleus.

*Beta minus decay*

Beta-minus Decay $= \beta$ decay

$\beta$ particle

Carbon-14        Nitrogen-14        Antineutrino   Electron

Beta Decay of $^{14}$Carbon Nucleus

6 protons        7 protons
8 neutrons       7 neutrons

1

In this case, the nucleus gained a proton and lost a neutron.

What happened? A neutron in the nucleus turned into a positive proton and a negative electron. The newly-formed electron comes flying out as a "beta-minus" particle. Also, this process creates an "antineutrino", which is a tiny, charge-less element that will become important later.

*Beta plus decay*

$\beta^+$ decay

$$p^+ \rightarrow n + e^+ + \nu$$

This is the opposite of beta-minus decay. The element takes one of its protons, splits it to a positron (a positive electron, this is antimatter), a neutrino, and a neutron.

Wait… But *how*?

i solated                                    anti

$$\textcircled{n} \longrightarrow \textcircled{p^+} + \textcircled{e^-} + \textcircled{\bar{\nu}}$$

$$M_n > M_{p^+} + M_{e^-} + M_{\bar{\nu}}$$

not possible

b/c cons of E

Beta-minus decay makes sense, because it would been energetically favorable as a neutron is *slightly* more massive and hence will loose some of the mass during beta-minus decay. But, during beta-plus decay, the reactants are less massive than the product (!!) — so thermally it won't really work out.

$$\textcircled{p^+} \not\rightarrow \textcircled{n} + \textcircled{e^+} + \textcircled{\nu}$$

same as reverse of n decay
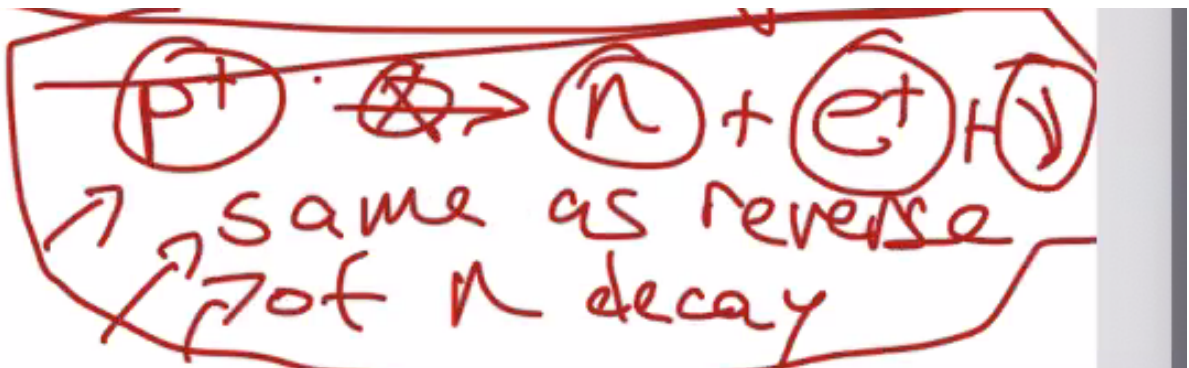
So, in order to actually create beta-plus decay, you have to shove the protons, antimatter, etc. together really fast with some kinetic energy. Or, this could happen spontaneously as long as the mass of the daughter atom is smaller than the mass of the parent (as in… as long as mass of daughter + mass of anti electron + mass of neutrino < mass of parent, this should work.)

To make sense of this, stop thinking that atoms' masses could be deducted by just counting the number of neutrons+protons.

*Electron capture*

Inside nucleus

$$p^+ + e^- \rightarrow n + \nu$$

"electron capture"

In this case, you will gain one neutron by simply capturing an electron out of thin air (the electron cloud) and merge it with a proton to form a neutron and an antineutrino.
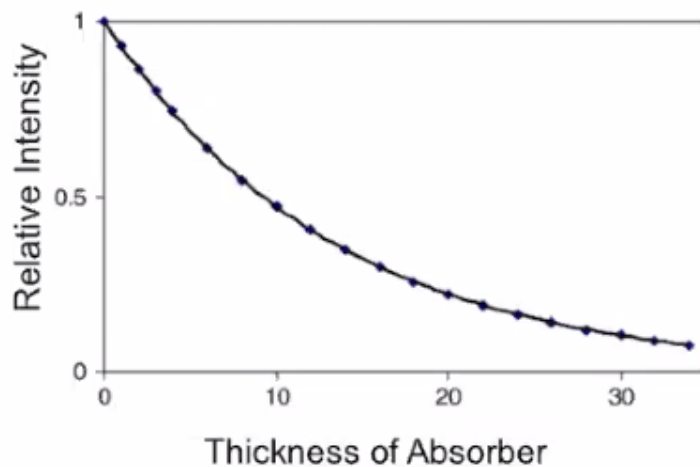
So, together…

β *decay:*

$$^{A}_{Z}N \rightarrow ^{A}_{Z+1}N' + e^- + \bar{\nu}$$
$$^{A}_{Z}N \rightarrow ^{A}_{Z-1}N' + e^+ + \nu$$
$$^{A}_{Z}N + e^- \rightarrow ^{A}_{Z-1}N' + \nu \, [\text{EC}]^{\dagger}$$

*Positron Capture*

This basically does not happen; it basically should work in a similar manner as does electron capture but the opposite.

You will need lots of pressure to squish two positive things together (Electrons + Protons) to fuse.

### 1.1.4 | **Absorbtion of Radioactivity**



The effect of absorbing material depends on its thickness, the type of radiation, and the energy of the radiation.

For radiation of a given type and energy, changing the thickness of the absorber results in the curve shown at left.

As the thickness of the absorber increases, the relative intensity of radiation exponentially, asymtotically decreases.

This is similar to the equatino of a dischanging capacitor; namely $e^{(\frac{-time}{\tau})}$

Instead of a smooth curve, we will decay by 2. We wil use it like a half life calculation:

$int = 0.5^{\frac{t}{T}}$, where $T$ is the thickness required to absorb 50%, and $t$ the thickness of the material. $int$ should be the relative intensity of the material — a percentage (0<=R<=1) that represents how much of the original, unhindered charge is disturbed.

Relative Intensity = 0.5 (t/T)

This is very much like a "half-life" calculation, where T

material has decayed), and t = actual passage of time

Remaining Material = 0.5 (t/T)

So when applied to absorption, for consistency, we sh

Relative intensity + half life problem 3:

Handwritten work:

$$\text{\#3)}$$

$$\frac{100}{R} = \cancel{R} \cdot \left(\frac{1}{2}\right)^{\frac{1}{T}}$$

$$R = \text{rate } w/ \text{ no absorber}$$

$$\frac{80}{R} = \frac{1}{2}^{\frac{1.7}{T}}$$

$$\left\} \text{ simult eq}\right.$$

$$T \simeq 2.17 cm$$

SOURCE

1cm   (0.7cm)

Detector →80

(?100)

$$\frac{80}{100} = \frac{1}{2}^{\frac{0.7}{T}}$$

### 1.1.5 | Stopping Rays

$\alpha$, $\beta$, and $\gamma$ rays are strong in that order — alpha rays could be stopped with less insulation than beta than gamma. HOWEVER, this is given that they all have the same *energy*. Different rays of the same energy would apply like this, but otherwise the energy matters especially for betas.

### 1.1.6 | Atomic Stability

**Please remember: most nuclei are stable!! Basically everyday things does not give you any meaningful amount of radiation.**

For relatively low protoned atoms, $(p < 30)$, stable nuclei is when $N \approx p$. For larger atoms, $N \approx < 1.5P$.

Vocab! Nucleon: neutron + proton.

The standard deviation of $N$ counts is the $\sqrt{(N)}$ if there is a uniformly random distribution.

## 1.2 | **Fission and Fusion**

Changes though **fission** (one nucleaus become two pieces, probably due to the parent absorbing a neutron, a.k.a. more equal parts of alpha decay) or **fusion** (two nuclei joining together to form one)

Due to conservation of energy, not every fission/fusion releases energy. If fission of A => B C releases energy, fusion of B+C => A wil not.

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You could think of the energy released as part of fission as the potential energy of a system.

The bottom row of "mass number" is nucleons w.r.t. the most common izotope

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Iron is a terriable way of getting some energy out of a atom because it has the lowest ever potential energy

Nuclear processes usually end up with Iron; like…

- If you are on the "blue"/"left" region, you release energy by fusioning into iron (add stuff up until you get to stable iron.)
- If you are on the "yellow"/"right" region, you release energy by fissioning into iron (split until you get to iron)

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But actually this is kind of a lie. It is actully a contour of all different izotopes, measured in "binding" energy and not PE. The **binding energy** is how forcibly the nucleus are bound together — the more tighly bound, the more energy it would require to break the binding.

Also, Binding Energy is measured in MeV, which convents to Joules with $1MeV = 1.6 \times 10^{-13}J$.

Nuclear fission is triggered by smushing a neutron into an atom.

For instance…

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# 2 | **Data Shape**

| Thickness | Count Rates | Count Time | Result: Normalized Count Rate |
| --- | --- | --- | --- |

This will, of course, result in a graph of thickness vs. count rate.

Goal: finding the best T and the +/- range that would fit the rates

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## 2.1 | **What is "best fit"**

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When data is uncertain, best fit should minimize $\sum \frac{D_i - M_i}{\sigma_i}^2$. Think as "how many standard deviations away" is the uncertainty. This is also called "pearson's statistic"

With this piece of information, at different discrete values of T, we could have a graph of T vs. S. At the minimum of that curve, that's the best fit!

Smin should be about # of datapoints - # of parametres

If Smin << # dp - # params, you did something wrong.

If Smin >> # dp - # params, sigma were probably underestimated/not the only sources of error

# 3 | **Lab**

1. Apply deadtime correction to both rate and unceartainty in the rate
2. Subtract (background, cor