α — Proton
β — electron

Radioactivity & Nuclear Reaction

Radioactivity:- The spontaneous disintegration of nucleus of an atom with the emission of one or more highly penetrating radiation like α, β particle & γ rays is called radioactivity.

Radioactive substance:- Those substance that exibits the phenomenon of radioactivity are called radioactive substance
Uranium, Radium, Thorium, Polonium, Neptunium etc.

Cause of radioactivity:- Unstable nucleus is the cause of radioactivity. There exists the attractive nuclear force between the nucleons inside the nucleus. There also exist the electrostatic repulsive force between the protons inside the nucleus. If the repulsive force is greater than the attractive force, the nucleus becomes unstable which is the cause for radioactivity.

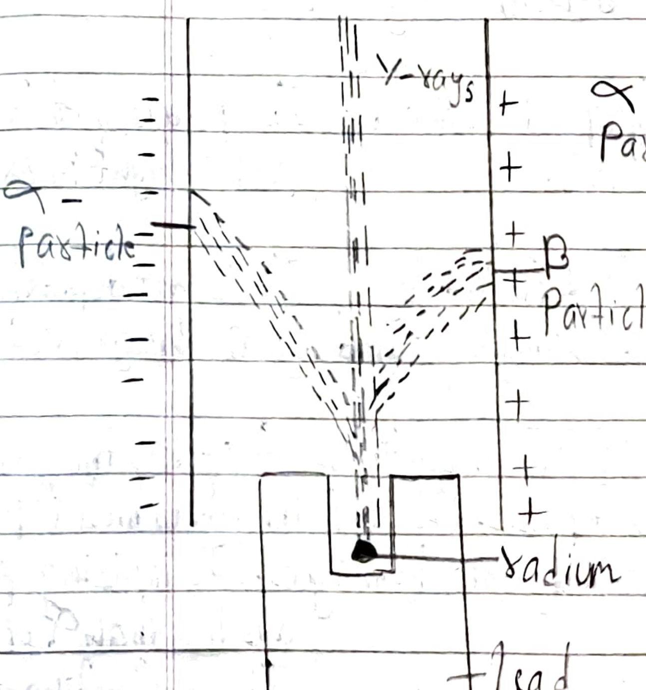
Electrical nature of radioactive radiation (Becquerel rays):

A simple exp. to demonstrate the electrical nature of radioactive radiation (Becquerel rays) as shown in figure. A small hole is drilled in the lead block & a piece of Radium is kept in it. As the lead can absorb the radiation before reaching the surface only, a narrow beam of radiation emerge out from it. The radiation is kept in electric & magnetic field & following observations are made:

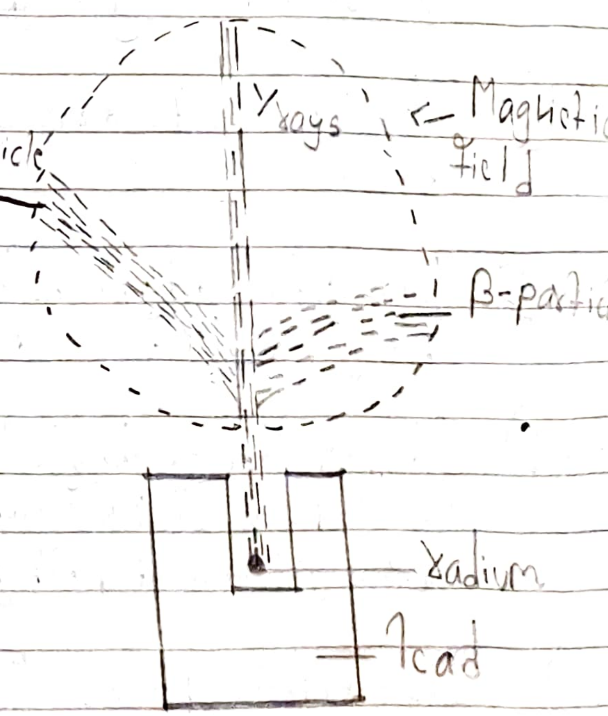
1. The component of radiation which bends towards the negative terminal in electric field consists of positive charge named as α - particle.

2. The component of radiation which bends towards the +ve terminal of electric field consists of negative charge named as β - particle.

3. The component of radiation which goes straight in electric & magnetic field without bending consists of neutral photons known as γ - rays.



Electric field



Properties of α-particle, β-particle & γ-rays

	α - Particle	β - particle	γ-rays
1	It is the nucleus of helium atom.	It is the fast moving electron of nuclear origin	It is the electromagnetic wave of very short wavelength
2	It has the charge of +2e or 3.2×10^{-19}C	It has the charge of -e or -1.6×10^{-19}C	It is chargeless
3	It has rest mass. i.e 6.4×10^{-27}kg	It has rest mass i.e 9.1×10^{-31}kg	It is massless
4	It's speed is of order 10^6 m/s.	It's speed is of order 10^8 m/s.	Its speed is equal to speed of light i.e 3×10^8
5	It is deflected by electric & magnetic field	It is deflected by electric & magnetic field.	It is not deflected by electric & magnetic field.
6	It ionizes the gas through which it passes. It's ionizing power is greater than β-particle	It ionizes the gas through which it passes. It's ionizing power is greater than γ-rays.	It ionizes the gas through which it passes. It's ionizing power is less than α & β
7	Its penetrating power is less than β-particle.	Its penetrating power is less than γ-rays.	Its penetrating power is greater than α & β.

Radioactive disintegration (Radioactive decay):-

→ The phenomenon of disintegration of the parent nucleus to form the daughter nucleus with the emission of 1 or more penetrating radiation is called radioactive disintegration.

The nucleus formed after radioactive disintegration is called daughter nucleus.

There are 3 types of radioactive decay:

① α-decay ② β-decay ③ γ-decay

① α-decay:- The type of radioactive disintegration in which the parent nucleus disintegrate to form daughter nucleus with the emission of α-particle is called α-decay.

mls. During α-decay the atomic number of the daughter nucleus is decreased by 2 unit while the atomic mass remains the same as the parent nucleus.

~~$_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4}$ + α-particle~~
~~parent nucleus~~ ~~daughter nucleus~~

$${}_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4} + \alpha\text{-particle}$$

Parent nucleus Daughter nucleus

$${}_{92}U^{238} \rightarrow {}_{90}Th^{234} + \alpha\text{-particle}$$
$${}_{88}Ra^{226} \rightarrow {}_{86}Rn^{222} + \alpha\text{-particle}$$
$${}_{84}Po^{208} \rightarrow {}_{82}Pb^{204} + \alpha\text{-particle}$$
$${}_{98}Th^{232} \rightarrow {}_{98}Ra^{228} + \alpha\text{-particle}$$

② β-decay:- The type of radioactive disintegration where the parent nucleus disintegrate to form daughter nucleus with the emission of β-particle is called β-decay.

There are three types of β-decay

① β^- decay ② β^+ decay ③ Electron Capture

① β^- decay:- The type of radioactive disintegration where the parent nucleus disintegrate to form daughter nucleus with the emission of β^- particle & antineutrino is called β^- decay.

During β^- decay the atomic number of the daughter nucleus increases by 1 unit while the atomic mass remains the same as the parent nucleus.

$$_{Z}X^{A} \rightarrow {}_{Z+1}Y^{A} + \beta^- \text{ particle } [{}_{-1}e^{0}] + \bar{\nu}$$

Parent — Daughter — Antineutrino

$[n \rightarrow p + e + \bar{\nu}]$

$${}_{6}C^{14} \rightarrow {}_{7}N^{14} + \beta^- + \bar{\nu}$$

$${}_{15}P^{32} \rightarrow {}_{16}S^{32} + \beta^- + \bar{\nu}$$

(2) β^+ decay:- The type of radioactive disintegration where the parent nucleus disintegrates to form daughter nucleus with the emission of B^+ particle & neutrino (has very less mass) is called B^+ decay.

During B^+ decay the atomic number of the daughter nucleus decreases by 1 unit while the atomic mass remains the same [$p \to n$ + positron + neutrino]

$$_{Z}X^{A} \longrightarrow {}_{Z-1}Y^{A} + \beta^{+} \text{ particle } [{}_{1}e^{0}] + \nu$$

Parent — daughter — positron — neutrino

$$_{11}Na^{22} \to {}_{10}Ne^{22} + \beta^{+} + \nu$$
$$_{9}F^{18} \to {}_{8}O^{18} + \beta^{+} + \nu$$
$$_{6}C^{11} \to {}_{5}B^{11} + \beta^{+} + \nu$$

(3) Electron Capture: The type of radioactive disintegration where the parent nucleus capture one of the orbital electron with the emission of neutrino is called electron capture.

Here the atomic number of the daughter nucleus decreases by 1 unit while the atomic mass remains the same as parent nucleus.

$$_{Z}X^{A} + {}_{-1}e^{0} \longrightarrow {}_{Z-1}Y^{A} + \nu$$

parent — electron — daughter — neutrino

$$_{4}Be^{7} + {}_{-1}e^{0} \to {}_{3}Li^{7} + \nu$$
$$_{19}K^{40} + {}_{-1}e^{0} \to {}_{18}Ar^{40} + \nu$$

(3) γ-decay:- α & β decay usually leaves the daughter nucleus in the excited state. If the excitation energy present with the daughter nucleus is not sufficient for further particle emission it releases in the form of γ-radiation which is known as γ-decay.

During γ-decay, the atomic weight & the atomic number of the daughter nucleus remains the same.

$$_{Z}X^{A*} \rightarrow {}_{Z}Y^{A} + \gamma\text{-rays}$$

$$_{38}Sr^{87*} \rightarrow {}_{38}Sr^{87} + \gamma\text{-rays}$$

VVI Laws of Radioactive Disintegration

(1) Radioactive disintegration is the random & spontaneous phenomenon. It is not influenced by the external factors like temperature, pressure, electric field etc.

(2) During the radioactive disintegration either the α-particle or the β-particle is emmitted from an atom. Emmissions of both types of particle at the same time is impossible.

(3) The rate of radioactive disintegration is directly proportional to the number of atoms present at that instant. This is called decay law.

Let N_0 be the no of atoms present on the radioactive substance at time $t = 0$. Let N be the no of atoms present on the sample after time 't'. Then the rate of disintegration,

$$\frac{dN}{dt} \propto N$$

$$\frac{dN}{dt} = -\lambda N$$

where 'λ' is the proportionality constant known as decay constant or disintegration constant. -'sign indicates that the number of atoms increases as the time increase.

$$\frac{dN}{N} = -\lambda dt$$

Integrating,

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

$$[\log_e N]_{N_0}^{N} = -\lambda [t]_0^t$$

$$\log_e N - \log_e N_0 = -\lambda t$$

$$\log_e \frac{N}{N_0} = -\lambda t$$

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

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

This is known as decay eqn. This shows the number of in the radioactive sample decreases exponentially with the time.

$\frac{dN}{dt} = -\lambda N$

$\lambda = \frac{\left(\frac{dN}{dt}\right)}{N}$

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Decay Constant (λ): Decay constant of the radioactive element is defined as the rate of disintegration of the radioactive substance per unit no of atoms present.

$$\lambda = \frac{-\frac{dN}{dt}}{N}$$

Half life (T or $T_{\frac{1}{2}}$): Half life of a radioactive substance is defined as time taken for radioactive substance to disintegrate half of the no of atom present in it.

It is different for different radioactive substance.

R/n betn Half life & Decay Constant:

-> let us consider a radioactive elements containing N_0 number of atom initally at time $t=0$. let λ be the decay constant of the radioactive element. After the Half life time T the no of left over atoms i.e $N = \frac{N_0}{2}$

using decay eqn,

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

$$\frac{N_0}{2} = N_0 e^{-\lambda T} \quad \left[\text{For Half life } N = \frac{N_0}{2}\right]$$

~~$\frac{1}{2} = \frac{1}{e^{\lambda T}}$~~

$$\frac{1}{2} = e^{-\lambda T}$$

$$e^{\lambda T} = 2$$

$$\lambda T = \log_e(2)$$

$$\lambda T = 0.693$$

$$T = \frac{0.693}{\lambda}$$

The half life of radioactive substance is inversely prop to its decay constant

Activity of radioactive substance:

→ Rate of disintegration of radioactive substance is called activity of radioactive substance.

Activity of Radioactive substance $(R) = \frac{dN}{dT} = -\lambda N$

$|R| = \lambda N$

i.e $R \propto N$.

If the activity of radioactive substance is R_0 when the initial no of atoms is N_0 after time 't' when no of atoms remains undecayed is N the activity is R.

$R_0 = \lambda N_0$ — ①

$R = \lambda N$ — ②

Dividing ② by 1

$$\frac{R}{R_0} = \frac{\lambda N}{\lambda N_0}$$

$$\frac{R}{R_0} = \frac{N_0 e^{-\lambda t}}{N_0}$$

$$R = R_0 e^{-\lambda t}$$

Mean life or Average life (T_{mean})

→ Mean life or Average life of the radioactive substance is defined as the ratio of sum of life of all the atoms present in the substance to the total number of atom present in the substance.

i.e

Mean life or Average life (T_{mean}) = $\frac{\text{Sum of life of all the atoms}}{\text{Total number of atoms}}$

It has been found average life of radioactive substance is reciprocal to its decay constant.

$$T_{mean} = \frac{1}{\lambda}$$

$$T_{mean} = \frac{1}{\left(\frac{0.693}{T}\right)}$$

$$T_{mean} = \frac{1}{0.693} \times T$$

$$T_{mean} = 1.44 \times T$$

where T = half life

* If 2gm of radioactive material having half life period of 50 years disintegrate. Find mean life of all given sample.

$$T = \frac{0.693}{\lambda}$$

$$\lambda = \frac{0.693}{50}$$

$$= 0.01386$$

$$T_{mean} = 1.44 \times 50$$

72 years

Units of Radioactivity

(1) Curie: It is defined as the activity of radioactive substance which gives 3.7×10^{10} disintegration per second.

$1 \text{ curie} = 3.7 \times 10^{10}$ dis/sec.

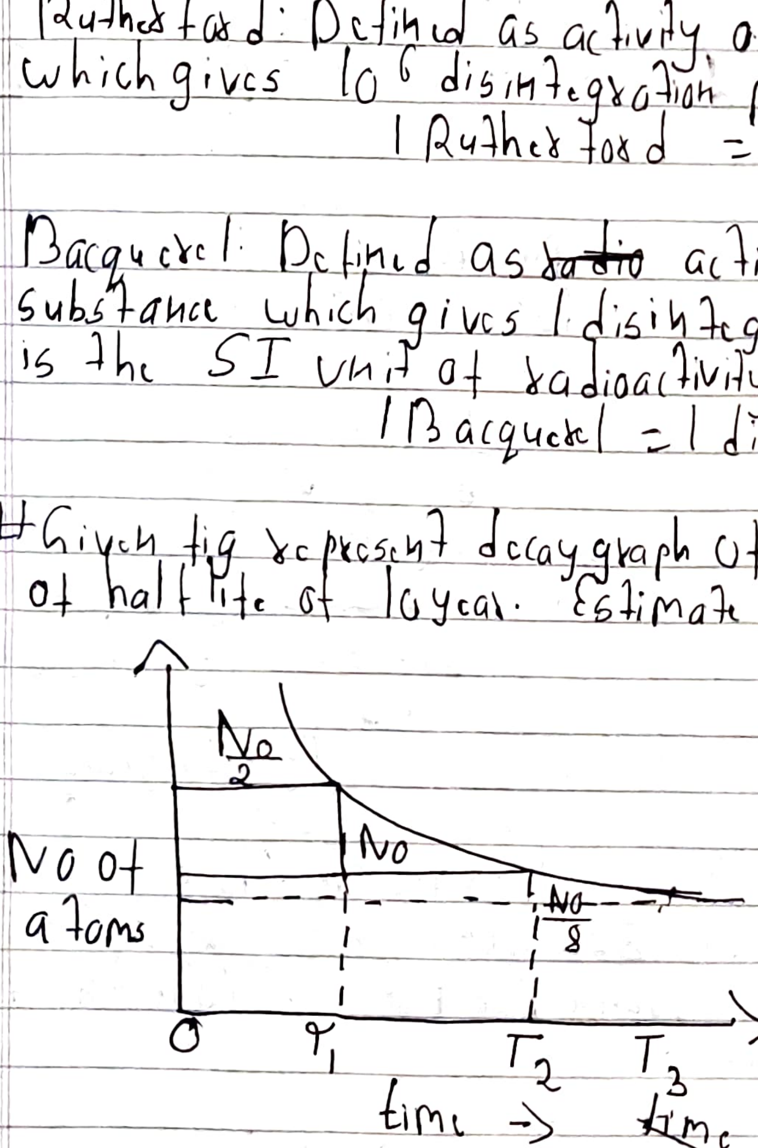
(2) Rutherford: Defined as activity of radioactive substance which gives 10^6 disintegration per second.

$1 \text{ Rutherford} = 10^6$ dis/sec

(3) Bacquerel: Defined as ~~radio~~ activity of radioactive substance which gives 1 disintegration per second. It is the SI unit of radioactivity.

$1 \text{ Bacquerel} = 1$ dis/sec.

Q SN # Given fig represent decay graph of a radioactive sample of half life of 10 year. Estimate value of T_3.



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→ Given,

initial no of atoms = N_0

time (T_3) = ?

Final number of atom $N = \frac{N_0}{8}$

Half life (T) = 10

decay constant (λ) = $\frac{0.693}{T} = \frac{0.693}{10}$ yrs

we know,

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

$$\frac{N_0}{8} = N_0 e^{-\lambda T_3}$$

$$\frac{1}{8} = \frac{1}{e^{\lambda T_3}}$$

$$e^{\lambda T_3} = 8$$

$$\lambda T_3 = \log_e 8$$

$$\frac{0.693}{10} T_3 = \log_e 8$$

$$T_3 = 30 \text{ years}$$

A GM counter used to measure the activity of radioactive elements shows 895 count per min & after 10 min it shows 327 count per min. Calculate the decay constant & half life.

→ Initial activity (R_0) = 895 dis/min

time (t) = 10 min

Final activity (R) = 327 dis/min

Decay const (λ) = ?

Half life (T) = ?

we know,

$$327 = 895 e^{-\lambda t}$$

$$327 = \frac{895}{e^{\lambda t}}$$

$$e^{\lambda t} = \frac{895}{327}$$

$$\lambda t = \log_e \left(\frac{895}{327} \right)$$

$$10\lambda = 1.0061$$

$$\lambda = 0.1 \text{ dis/sec}$$

Again,

$$T = \frac{0.693}{\lambda} = \frac{0.693}{0.1} = 6.93 \text{ min},$$

(1) In a given sample two radioactive isotopes A & B are initially present in the ratio of 1:4. Half life of A & B are 100 years & 50 years resp. Find the time after which the atoms of A will be equal to B

A

initial no of atom = N_0

Half life (T) = 100 years

$$\lambda_A = \frac{0.693}{100} /\text{yrs}$$

B

Initial no of atom = $4N_0$

Half life (T) = 50

$$\lambda_B = \frac{0.693}{50} /\text{yrs}$$

let After time 't' final no of atoms of A & B are equal

$$N_0 e^{-\lambda_A t} = 4 \times N_0 e^{-\lambda_B t}.$$

$$e^{-\lambda_A t} = 4e^{-\lambda_B t}$$

$$e^{-\lambda_A t} = \frac{4}{e^{-\lambda_B t}}$$

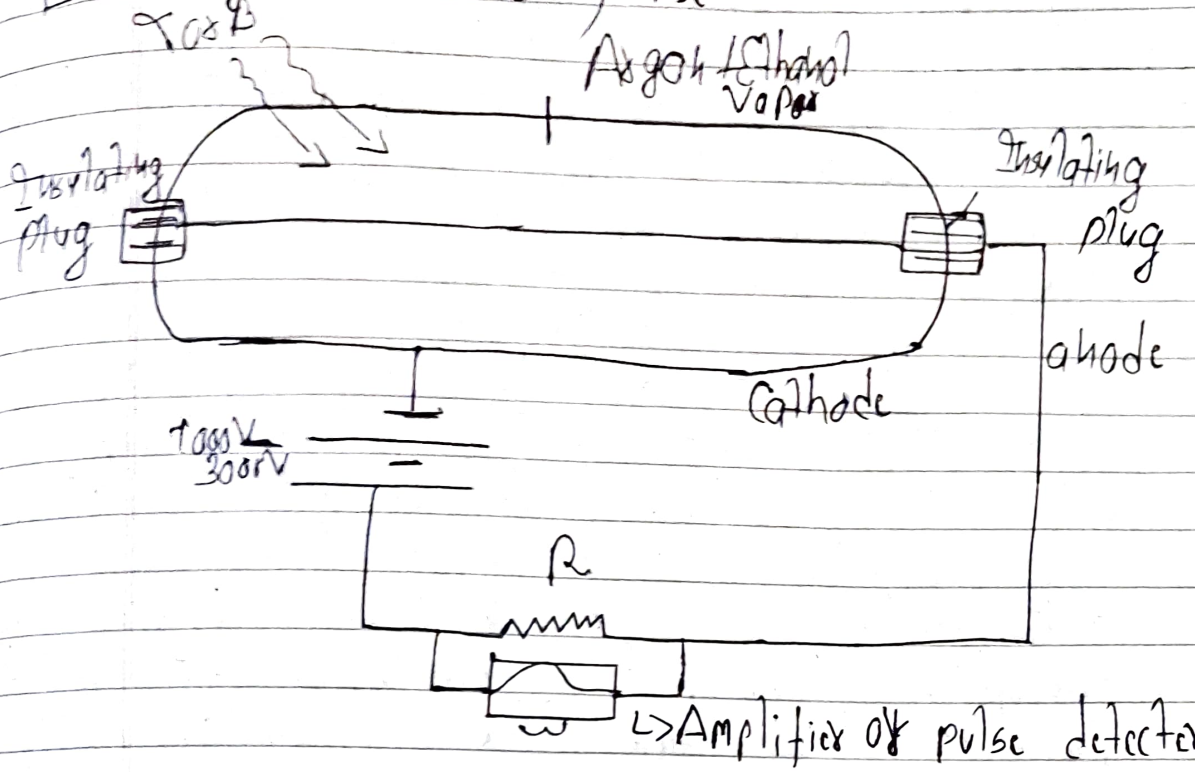
$$e^{-\lambda_A t + \lambda_B t} = 4$$

$$-\lambda_A t + \lambda_B t = \log_e (4)$$

$$t(\lambda_B - \lambda_A) = 1.386$$

Radioactivity

Geiger-Muller (GM) tube



-> The device used to detect nuclear radiation is called detector. GM counter is one of the simplest detector of nuclear radiation.

When a charged particle like α or β enter the GM tube, it basically leads to ionization. Now the charged particle feels accelⁿ due to electric field & moves to respective terminal. During this motion electron transfer energy to existing charged particle which leads to further ionization. This process continiously goes on & large no of excited ion are created. When the electron reach to anode, they are absorbed by anode & passes through the load resistance & reach cathode. There they recombine with the +ve ion. This whole process creates 1 count.

Radio carbon Dating:-

-> The process of dating an ancient object that is the age of archaeological specimen by analyzing the proportion of $_6C^{14}$ to $_6C^{12}$ in a specimen is called carbon dating.

The half-life of $_6C^{14}$ is 5730 yrs & is used in archaeological dating. All the plants & living organisms contains fixed ratio of $_6C^{14}$ & $_6C^{12}$. When they die, the intake of $_6C^{14}$ stops & its decay starts while $_6C^{12}$ remains unchanged. By studying the ratio of the concentration of $_6C^{14}$ & $_6C^{12}$ present in dead body, the age of specimen is estimate.

Diff between natural radioactivity & artificial radioactivity

	Natural Radioactivity	Artificial Radioactivity
①	It is the process of spontaneous emmission of radiation by heavy element occured in nature.	It is the process of spontaneous emmission of radiation induced in radioactive element.
②	It emits strong & highly penetrating nuclear radiation.	It emits nuclear radiation of less penetrating power.
③	Natural radioactive element are heavy & unstable.	Artificial radioactive elements are lighter than natural radioactive element.
④	Eg: U^{238}, Th^{234} etc	Eg C^{14}, Na^{24}, etc.