1A. PARTICLES AND MATTER

Nucleons are approx **1800x** mass of electron (nucleon = proton and neutrons)

Max number of electrons in a shell = 2 x (n^2) (max is 32, i.e. n = 4)
Note: each subshell can only hold 2 electrons, therefore number of subshells correspondingly increases.

K 2 electrons

L 8 electrons

M 18 electrons

Binding energy increases with shells closer to nucleus and with increasing protons in a nucleus

Energy of the actual electron (energy level of electrons) decreases as it is closer to the nucleus as the binding energy increases.

Radiation: **Mechanism** of energy transfer. Can be particulate or wave mechanisms of transfer. (particle-wave duality)
Particles are simply packets of fixed amounts of energy with no mass
These packets are called quanta
Energy of each quantum is proportional to *v* (freq)

E= h*v* (h = Plancks constant 6.6 x 10^-34 Js)

Gamma rays and X rays: same freq, energy, wavelength.
SOURCE / ORIGIN DIFFERENT: Gamma rays come from nucleus. X rays from electron shells

ELECTRON INTERACTIONS WITH MATTER/target = produce a radiation beam made of photons

ELECTRONS WITH ELECTRON SHELLS
Characteristics X rays are unique to each element. As inner shell electrons are displaced by an incoming electron (which in turn loses energy to the inner shell electron and gets scattered), outer shell electrons drop down and diff between BE of levels is released as X rays - this is a unique quantum of energy.

ELECTRONS WITH NUCLEUS
Brehmstraulung. Braking of electron due to nucleus (positive charge) when in vicinity, and energy lost as photons/Xrays. Can be a wide range

ELECTRONS COLLIDING WITH NUCLEUS
Rare

A radiation beam produced by electrons impacting on a target contains photons of a wide range of energies. Brehmstraulung and characteristic radiation both contribute

The beam energy is the MAXIMUM possible energy of a photon in that beam = max energy of incoming electrons on target

THE AVERAGE ENERGY of photons in a beam is approx 1/3rd of max energy
Beam fluence: No. of photons passing through unit area.

ATTENUATION OF RADIATION BEAM IN MATTER
u = linear attenuation coefficient (reduction in intensity per unit length)
m = u/density = mass attenuation coefficient (reduction in intensity per unit mass)

Electromagnetic radiation or PHOTONS interacting with MATTER

Scattered with or without energy change (with energy change = Compton)
Absorbed - Photo electric effect.
Absorbed with Pair production

PHOTO ELECTRIC EFFECT: PE effect.
ALL Energy of photon is absorbed by orbital electron. (usually inner shell electron)
This electron either jumps shells or escapes atom
Photon ceases to exist after PE effect as all its energy is absorbed
PE proportional to Z^3 or E^-3

COMPTON SCATTER:
Not all energy of photon is absorbed. Some energy is given up and the incident photon is scattered. The electron absorbing energy is also released.
Proportional to electron density
((The electron density for almost all materials is constant at approximately 3 × 1023 electrons per gram because N :
Z is almost constant. The exception is hydrogen, which with one proton in the nucleus has an electron density of around 6 × 10 raised to 23 electrons per gram.)
Independent of Z, Inversely proportional to E
Incident Photons exists after Compton scatter

Pair production
Min energy of incident photon 1022kEV or 1.022 MeV
Only occurs in presence of an electric field (cannot occur in vacuum)
A high energy photon splits into an electron and positron (energy into mass)
Increases in proportional to Z and E
Incident Photon does not exist after that (totally converted to mass and KE of electron and position pair)
Not really seen in patients, but may happen in shielding

Note: A positron and an electron can also interact and annihilate and produce 2 photons (2 photons produced to conserve momentum of 2 particles)

So one photon —> 2 particles (PAIR PRODUCTION) ——and note later then 2 particles (which may be different to original two) can join to produce 2 photons

p.s. Photonucleear interactions can occur at very very very high energies. A photon can strip a nucleon from the nucleus.

AUGER EFFECT
Outer shell/high energy e ——> moves to lower energy state/inner orbital shell ——> excess energy released either as a photon or is directly transferred to another electron in the atom which is released as an Auger electron

SCATTER:
For low E beams, scatter in all directions
For higher E beams - scatter predominant in forward direction. e.g. MV beams on linac

SECONDARY ELECTRONS:
Produced after EM interacts with matter via PE or Compton and produces secondary electrons. These secondary electrons deposit the dose in tissue via electron matter interactions

CHARGED PARTICLE OR ELECTRON INTERACTIONS WITH MATTER (eg. in a patient)
Photon beams produce secondary electrons which interact with matter and deposit energy

Charged particles have an electric field and are much more likely to interact with matter (as compared to uncharged particles like photons)
May interact a million times before losing all KE

COLLISIONAL INTERACTIONS:
with electrons or nucleus
with electrons : hard or soft

1. Charged particle interaction with orbital electrons: excitation or orbital electrons to higher state or ionisation. Incident Charged particle is scattered.

2. Interaction with nucleus of atom: Elastic collisions (NO LOSS OF KE in matter, like a snooker ball, just a scatter or brushes past nucleus with some minimal transfer of energy but really KE is not lost), or inelastic collisions (KE lost and deposited in matter, charged particle interacts with nucleus and is absorbed for a short excited period of time, and then released or scatter, KE might be lost as a gamma ray photon)

COLLISIONAL LOSSES with orbital electrons CAN BE Ionisation or excitations. Both of these can be HARD OR SOFT
Soft collisions (ionisations) are most common. Ionisations or excitation can occur but low KE transfer states. Incident Electron passes quite far from nucleus and really interacts with coulomb forces of atom as a whole
Hard collisions: incident electron interacts with orbital electrons in close proximity. Large amounts of KE transfer. Released electrons can have high KE (delta rays)

RADIATIVE INTERACTIONS
Brehmstraulung

LET
For a charged particle in a medium = **energy lost to collisions** per unit distance

Stopping power is Energy lost per unit length
Sum of collisional and radiative losses

RBE: Relative Biological Effectiveness. RBE of Type of radiation R is the Dose of reference radiation X (usually 250keV X rays) required to cause a certain biological effect to the Dose of Radiation R required to cause the same effect.

As LET increases, RBE increases —- > up to a peak (100keV/micrometer LET peak) Thereafter as LET increases, RBE decreases. This is explained by the fact that at higher LET, the energy is deposited in the medium over a very narrow distance. If this distance is less than the diameter of DNA or less than 2 nanometers, then the energy deposited is LOST and does not cause further DNA damage.

STOPPING POWER of medium:

Medium properties	**Particle properties**
Proportional to a. Electron density b. Ratio of Z/A c. Physical density	a. Proportional to Z2 (of particle, really relates to the charge of the particle given the same masses) b. Inversely proportional to Velocity ^2 or KE (KE proportional to velocity square) c, Proportional to mass of particle (really related to situations where heavier vs lighter particles with same charge)

Range of charged particle is inversely proportional to Z/A of medium, and inversely proportional to particle mass (less mass greater range, and less stopping power) (Range is distance the charged particle travels before stopping or losing all KE)

Low energy particles	**High density materials**
More lateral (large angle) scatter	More lateral scatter (large angles) (decreased forward beam)
Less particle range	Less particle range

Bragg peak occurs as the interaction cross section of a charge particle increases as its energy decreases due to collisional and radiative losses.
Hence peak near the end for protons and neutrons

Low electron mass means large angle scattering and no real Bragg peak

PROTON BEAMS:
How to get protons to cover target if the Bragg peak is very narrow:

1. Increase Scatter or spread out the bragg peak
2. Spot scanning - multiple beams of different energy with different bragg peak distances.

Proton energies used for deep seated tumours 200-250MeV
For Eyes (50-100MeV)
RBE 1.1

Neutrons beams:
Uncharged but high LET radiation
RBE 1.5 to 5