

{ \pm }-{Matter} Interactions

- Cross Section of Ball is $\pi R^2 \sim$ Probability of Collision
- α Range/Path Length is 10^{-5} m
- e Range/Path Length is 10^{-3} m
- α almost always interact with atomic- e
- e mostly interact with atomic- e and sometimes atomic nuclei
- α travel in straighter lines
- e bounce and scatter more often
- α lose small fractions of energy on collisions
- e lose large fractions of energy from collisions and bremsstrahlung $\propto Z$
- At rel. speeds ($> mc^2$), all part. lose minimum ~ 1 KeV/cm in air (min. ionizing particle)

Photon Interactions (Emits Electrons)

Low E_γ (few KeV)	Z^4	γ -{Atom}	Photoelectric Absorption	$E_{\text{emit}, e} = E_\gamma - E_{\text{bind}}$
Med E_γ (tens KeV to few MeV)	Z	γ -{Electron}	Compton Scattering	$\Delta\lambda_\gamma = \frac{h}{mc}(1 - \cos\theta)$
High E_γ ($> \text{tens MeV}$) ($E_\gamma > 2m_e c^2$)	Z^2	γ -{Nucleus}	Pair Production	$\gamma \rightarrow e^- + e^+$

Particle Energy Detection

- { \pm } (mainly electrons) goes past a scintillator with a high Z to increase the γ -interaction cross section (e.g., NaI/Tl, where I has a high Z)
- e produces visible light propto its energy when it goes past the scintillator.
- The visible light is directed into a photomultiplier tube, producing a current and voltage.
- An analyzer reads the voltage, ideally propto the original photon that produced the electron.
- The detector is calibrated by irradiating it with a light source of known energy.

Radioactive Decay/Lifetime

- $N = N_0 e^{-t/\tau}$
- $\tau = \text{Lifetime} \Rightarrow t_{\text{half life}} = \tau \ln 2$
- $\frac{1}{\tau} = \sum_i \frac{1}{\tau_i}$ (multiple decay “channels”)

Lasers

- Generally, an Optical Pump provides energy to push a particle state from ground state (0) to (3), which quickly drops to metastable state (2), and more slowly drops to (1). As it drops from (2) to (1), its photon is absorbed by another particle in (2), which emits two photons to be absorbed by another in (2), which multiplies exponentially. All photons end up with the same freq. and phase. If (0) and (1) are close enough, it's called 3-level instead of 4-level.
- Solid State (Nd:YAG) - Y in Al Garnet, with Nd (sometimes replacing the Y) having 4-levels
- Collisional Gas (He-Ne) - Collisions between the two are the level transitions, of which there can be many.
- Molecular Gas (CO₂) - Triangle shape provides vibrational energy levels; also is cheap
- Dye Laser - A dye dissolved in liquid. Chain of carbon transfers electrons (also gives color).
- Semiconductor - Pumping excites e from the bottom of the conduction band to the holes at the top of the valence band, releasing recombination radiation.
- Free Electron - e accelerate back and forth between an E -field, releasing bremsstrahlung. No energy levels but there's still amplification.
- Interferometers - Split light in two, recombine to see interference from diff. path lengths.

Decay Types

Strong Force - Usually 10^{-23} sec.

EM Force - Usually 10^{-18} - 10^{-16} sec. and photons

Weak Force - Usually 10^{-10} - 10^{-8} sec. and neutrinos

Nuclear Forces

- Quarks are *confined* to color neutral *color singlets*.
- First proton excited state is Δ^+ .
- Mesons have int. spin (0,1) and Baryons have half-spins (1/2, 3/2).
- $(n \rightarrow p^+ e^- \bar{\nu}_e)$ Neutron Decay takes ~ 15 min., except with Protons/SF in Nucleus
- Nuclear Diameter \sim femptometers (10^{-15} m).
Atomic Diameter \sim picometers (10^{-12} m).
Solid Atoms Distance \sim angstroms (10^{-10} m).
Air Atoms Distance \sim nanometers (10^{-9} m).
Bacteria Width \sim micrometers (10^{-6} m).
- Gamma radiation comes from excited nuclei states and don't change their composition.
- Heavy Nuclei Decay to Lead.

Symmetries, Conservation, and Recent Discoveries

- Conservation of Baryon Number and Each of the Three Lepton Numbers.
- Charge, Baryon, and Lepton cons. are symmetries by some multiplication of phase $e^{i\alpha}$.
- $\{\alpha\}$ is cont. \rightarrow it is a Continuous Symmetry.
- $\alpha \neq \alpha(x) \rightarrow$ it is a Global Symmetry.
- $\alpha = \alpha(x) \rightarrow$ it is a Gauge Symmetry.
- C, P, T are Discrete Symmetries.
- All Lorentz Invariant Theories must be symmetric under CPT .
- Weak Interaction is Maximally Parity-Violating (only L-hand decays, shown in ^{60}Co decay).
- Higgs Boson Mass = 125 GeV.
- Neutrino Oscillations show Mass Differences (not exact values).
- Dark Matter might be WIMPS and might interact with WF; galaxies spin faster + Bullet Cluster.

Crystal Structure (fuckin hell)

- 14 Bravias Lattices, but only these three conventional unit cells are important here:

	Vertex Dist.	Primitive Unit (idgi)	Volume (idrk)
Simple Cubic	a	Cube	$V = a^3$
Body-centered cubic (BCC)	$\frac{\sqrt{3}}{2} a$	Octahedron (2 square pyramids)	$V/2$
Face-centered cubic (FCC)	$\frac{\sqrt{2}}{2} a$	Parallelepiped	$V/4$

- The Fourier Transform of a lattice is it's *reciprocal* or *dual*.
- Dual Side Length = $\frac{2\pi}{a}$
- Dual(Simple Cubic) = Itself
- Dual(BCC) = FCC; Dual(FCC) = BCC.
- Dual(Hexagonal Lattice [HL]) = HL rotated through a 30° angle.
- Primitive Unit of Dual(X) is called the (*1st*) *Brillouin Zone* of X .

Electrons in Metals (Fermi)

- e have Momentum in Fermi Sphere/Sea, and free e in Fermi Surface with $|k| = k_F$.
- $k_F = (3\pi^2)^{1/3} n^{1/3}$ (n = electron density)
- Fermi Energy: $E_F = \frac{\hbar^2 k_F^2}{2m}$
- Density of States: $\rho(E) = \left(\frac{V\sqrt{2}}{\pi^2 \hbar^3}\right) m^{3/2} E^{1/2}$
(# e States for E)
- Total # e : $N = \int_0^{E_F} \rho dE \Rightarrow \rho(E_F) = \frac{3}{2} \frac{N}{E_F}$
- # Conducting e : $N_C \approx \rho(E_F) k_B T \sim \frac{N k_B T}{E_F}$

Semiconductors/Superconductors

- Energy is needed for e to cross the band gap from valence to conduction.
- Higher T thus needed to increase conductivity and electron energy/density.
- n-type doping/junction: 4 e^- valence in Si/Ge/Sn (group 14), doped with 5 e excess P/As/Sb (group 15).
- p-type doping/junction: e Hole $^+$ excess by doping (group 14) with 3 valence B/Al (group 13).
- Meissner Effect: Persistent I on surface cancel internal B field exponentially from surface. Akin to giving a photon mass to decrease the EM force strength.
- Cooper Pair (BCS Theory): e are Paired together (like bosons) to get lower-than- E_F energies.

Astrophysics

- $ds^2 = dt^2 - a(t)^2(dx^2 + dy^2 + dz^2)$ a is scale factor of COSMO, not matter-filled space
(space expanding $\rightarrow a$ is increasing func. of t)
- Cosmo-Expansion γ Redshift: $\frac{\lambda_0}{\lambda_T} = \frac{a(\text{today})}{a(T)}$ T = time before
- Blackbody Cooling: $2\lambda_{\max} \propto \frac{1}{T/2}$ (cosmos 2x means temp. 1/2x)
- Hubble's Law: $v_{\text{recess.}} = H_0(t)D$ (2x distance is 2x speed)
- Redshift as Time: $z(T) = \frac{\lambda_0}{\lambda(T)} - 1$ (at "redshift 3" means time in past when λ was 400% smaller)
- Cosmo \neq Doppler Redshift: Speed \leftrightarrow Doppler
Distance \leftrightarrow Cosmo

Nobel Prizes

- 2017 (Gravity Wave Detection): LIGO with 10^{-18} m shift with laser crossing many times.
- 1993 (Gravity Wave Indirect): Measured Pulsar Pair Orbit energy loss from GW.
- 2015 (Neutrino Oscillations): WF Hamiltonian (Flavor) doesn't commute with Free Particle (momentum/mass). Sun makes ν_e , but less are detected on Earth.
- 2014 (Blue LED): GaN semiconductor has direct band gap of $(3.4 > 3)$ eV, for UV light.

Memorize Numbers/Facts

- $c = 3\text{E}8 \text{ m/s}$
- $h = 6.626 \text{ E-34 Js}$
- $\hbar c = 200 \text{ MeV} \cdot \text{fm}$
- $\alpha = 1/137 = .0073$
- $a_0 = 42.9 \text{ pm}$
- $m_e = .511 \text{ MeV}/c^2$
- $E_n = -13.6 Z \frac{Z^2}{n^2} \text{ eV}$
- $n_A = 6.02\text{E}23$
- $k_b : 300\text{K} = \frac{1}{40}\text{eV}$
- $1 \text{ atm} \approx 100 \text{ kPa}$
- $1 \text{ atm}, 300\text{K} \leftrightarrow 22.4 \text{ L}$
- $1 \text{ L} = 1\text{E}3 \text{ cm}^3 \text{ or mL}$
- $1 \frac{\text{g}}{\text{cm}^3} = 1\text{E}3 \frac{\text{kg}}{\text{m}^3}$
- $c_{\text{water}} = 4.18 \frac{\text{J/K}}{\text{g}}$
- $1 \text{ cal} = 4.18 \text{ J}$
- $v_{\text{sound}} = 340 \text{ m/s}$
- Rel. IG : $C_V = 3k_b$
- $T_{\text{CMB}} = 2.725 \text{ K}$; $\lambda_{\text{CMB}} = 1.9 \text{ mm}$
- $T_{\text{Sun}} = 5000 \text{ K}$; $\lambda_{\text{Sun}} = 550 \text{ nm}$
- $\text{BE}_{\text{Nucleon}} \sim \text{MeV}$; $E_{\text{part. accel}} \sim \text{GeV}$
- $E_{\text{UV}} \sim \text{eV}$; $E_{\text{X-ray}} \sim \text{keV}$
- $E_n = \frac{-\alpha^2(Zm_e)c^2}{2} \frac{Z^2}{n^2} = \frac{\hbar^2 k_n^2}{2m_e} Z \frac{Z^2}{n^2}$
- $\alpha = \frac{kq q}{\hbar c}$
- $a_0 = \frac{\hbar^2}{m_e k q q}$
- $T^2 \propto a^3$
- $D \sin \theta = 1.22 \lambda$
- $\lambda_{\text{max}} = \frac{2.9\text{E-3 m}\cdot\text{K}}{T}$
- $K = C + 273.15^\circ$
- $v_{\text{sound}}^2 = \frac{K}{\rho} = \frac{\gamma P}{\rho} = \gamma \frac{NkT/V}{Nm/V} = \frac{\gamma kT}{m}$