SCINTILLATION DETECTORS

SCINTILLATORS SHOULD

1. CONVERT K.E. INTO LIGHT WITH HIGH EFF.
2. CONVERSION SHOULD BE LINEAR
3. SCINT. MATERIAL SHOULD BE TRANSPARENT TO ITS EMITTED LIGHT
4. PERSISTENCE SHOULD BE SHORT
5. EASY TO MANUFACTURE, ROBUST, etc.

SCINTILLATING MATERIALS:

ORGANIC SCINTILLATORS. FLOURESCENCE PROCESS ARISES FROM TRANSITIONS IN THE ENERGY LEVEL STRUCTURE OF A SINGLE MOLECULE, & THEREFOR CAN BE OBSERVED FROM A GIVEN MOLECULE IN ANY PHYSICAL STATE.

• EX: ANTHRACENE IS OBSERVED TO FLOURESCE AS AS SOLID POLYCRYSTALINE, AS A VAPOR, AS A COMPONENT OF ~~a~~ A MULTICOMPONENT SOLUTION. (AS OPPOSED TO CRYSTALINE INORGANIC SUCH A NaI — REQUIRES CRYSTAL STRUCTURE FOR SCINT PROCESS)

— MOST ARE EXCITED ELECTRON STATES

~~SPIN~~ SINGLET (SPIN 0)
TRIPLET (SPIN 1)
} ENERGIES 3→4 eV

FLOURES DECAY TIMES FOLLOW

$$I = I_0 e^{-t/\tau}$$

τ — flour decay const.

$\tau \approx$ a few nanoseconds.

• EX STILBENE

LIQUID ORGANIC SCINT COUNTERS

- + λ- SHIFTER TO MAXIMIZE LIGHT DETECTION
- DISOLVE RADIONUCLIDE IN IT FOR 100% EFF
  - NESC FOR LOW-LEVEL β^- ACTIVITY

    C-14 TRITIUM

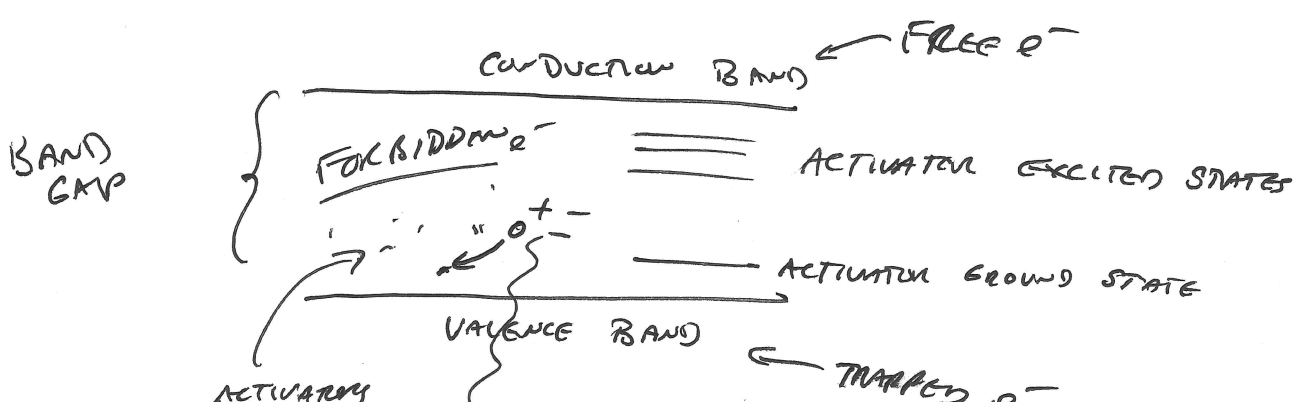
PLASTIC SCINT

ORGANIC SCINT, LIQUIFIED & POLYMERIZED. INTO A SOLID PLASTIC. RODS, CYL, FLAT SHEETS

GOOD FOR COMPLICATED GEOMETRIES, LARGE AREAS, VOLUMES.

INORGANIC SCINTILLATORS

SCINT MECHANISM IN INORGANIC MATERIALS DEPENDS ON THE ENERGY STATES DETERMINED BY CRYSTAL LATTICE.



ACTIVATORS CREATE SPECIAL SITES WITHIN THE FORBIDDEN BAND

$T_{1/2}$ OF EXCITED STATES ~ 10^{-7} seconds

SCINTILLATION EFF

~ 3x BAND GAP ENERGY TO CREATE 1 e⁻-HOLE PAIR.

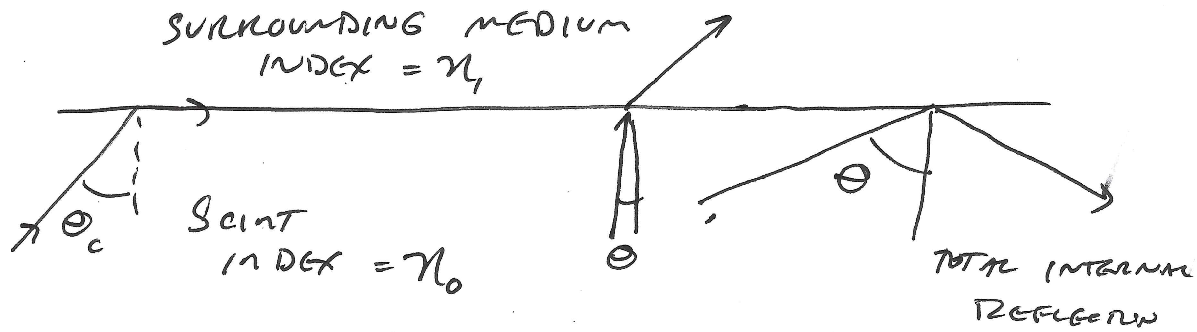
- IN NaI 20 eV MUST BE LOST TO CREATE 1 e⁻- HOLE PAIR
- 1 MeV PARTICLE → 5×10^4 e⁻-HOLE PAIR
- NaI (Tl) ABS SCINT EFF IS ~12%

- ACTIVATORS SATISFY THE TRANSPARENCY REQUIREMENT

- NaI (Tl) ~~MOST~~ HIGH LIGHT YIELD, + ENERGY RESPONSE TO e⁻ + GAMMA VERY LIN.

- BISMUTH GERMANATE (BGO) $Bi_4 Ge_3 O_{12}$
  - LIGHT YIELD 10-20% of NaI
  - BUT HIGH DENSITY ~ 7.3 g/cm³
  - + MORE RUGGED
  - HIGH GAMMA RAY COUNTING EFFICIENCY (PORTABLE INSTRUMENTS)

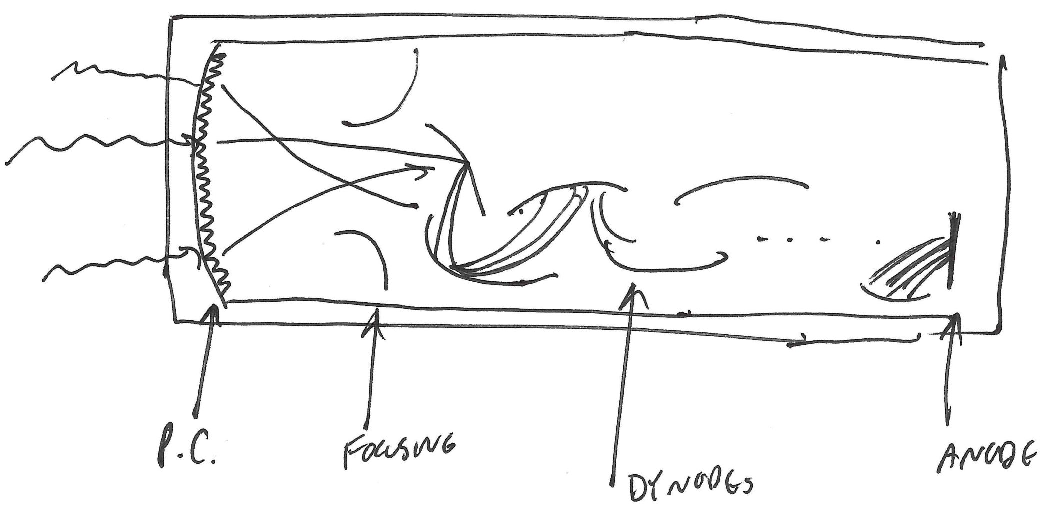
UNIFORMITY OF LIGHT COLLECTION



$$\theta_c = \sin^{-1}\left(\frac{n_1}{n_0}\right)$$

OPTICALLY COUPLED LIGHT SENSING DEVICE.

PMTs



1. ABSORPTION OF INCIDENT PHOTO + XFER OF ENERGY TO AN e^-
2. MIGRATION OF e^- TO THE SURFACE
3. ESCAPE OF THAT e^- FROM THE SURFACE

W.F. $\sim 3\,eV$ (AS LOW AS 1.5–2 eV)

PMT $QE = \frac{\#\ \text{PHOTOELECTRON EMITTED}}{\#\ \text{INCIDENT PHOTONS}}$

TYPICAL PMT ~ 20%

PMT GAIN ARISES FROM SECONDARY e^- EMISSION

e^- LEAVING PHOTOCATHODE HAVE KE ~ 1eV

HOLD 1ST DYNODE @ +100V, CREATION OF e^- @ DYNODE ~ 2-3eV, SO 1 PHOTO e^- → 30 e^- per 100V OF ACCELERATING VOLTAGE

$$\delta = \frac{\#\ \text{SECONDARY } e^-\ \text{EMITTED}}{\text{PRIMARY } e^-\ \text{INCIDENT}}$$

PRACTICAL MATERIALS SUCH AS BeO, MgO, Cs_3Sb

$\delta \approx$ 4 ~ 6 FOR 100V PER DYNODE STAGE

OVER ALL GAIN $= \alpha\, \delta^N$ ← NUMBER OF STAGES

α: FRACTION OF ALL e^- COLLECTED BY MULTIPLIER STRUCTURE ~ 1

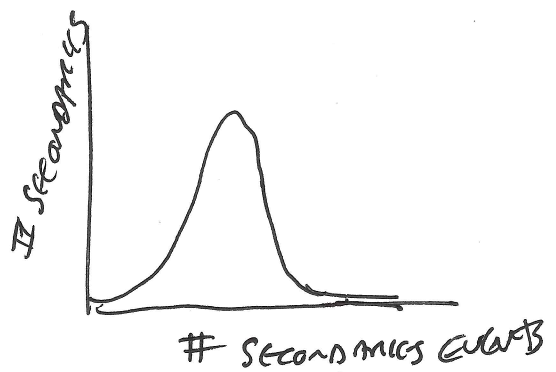
10 STAGE TUBE, $\delta = 5$: GAIN $= 1 \cdot (5)^{10} = 10^7$

e^- MULTIPLICATION STATISTICS

2^{nd} EMISSION IS STATISTICAL + WILL VARY ABOUT ITS MEAN VALUE

1^{st} DYNODE MEAN VALUE δ WITH STD DEV $\sqrt{\delta}$
COMPOUNDED OVER N STAGES
AMPLITUDE δ^N VARIANCE

$$\frac{1}{\delta} + \frac{1}{\delta^2} + \frac{1}{\delta^3} + \dots \frac{1}{\delta^N} \cong \frac{1}{\delta - 1}$$



LINEARITY: CONSTANT 1 photon → 10,000 photons

EXAMPLE: SCINTILLATION EVENT LIBERATES ~ 1000 photons

GAIN 10^6 SO $10^9 e^-/\text{Pulse}$ SAY EVENT RATE $10^5/\text{sec}$

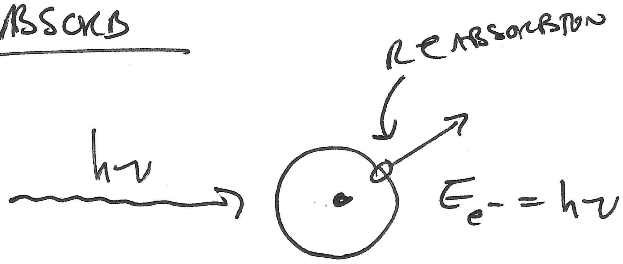
$$I_{AVG} = 10^9 \frac{e^-}{\text{pulse}} \cdot 1.6 \times 10^{-9} \frac{\text{Coul}}{e^-} \cdot 10^5 \frac{\text{Pulses}}{\text{Second}} = 0.016 \text{ mA}$$

SPECTROSCOPY

3-WAYS GAMMAS INTERACT

- PHOTOELECTRIC ABSORBTION
- COMPTON SCATTERING
- PAIR PRODUCTION

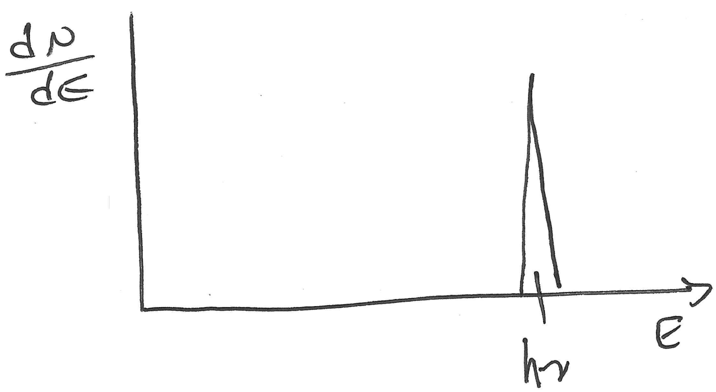
P.E. ABSORB



$$E_{e^-} = h\nu - E_b$$

↑ BINDING ENERGY

TOTAL ENERGY ABSORBTION IS THE IDEAL PROCESS IN MEASURING ORIGINAL GAMMA RAY ENERGY



COMPTON SCATTERING

ENERGY OF SCATTERED GAMMA RAY IS:

$$h\nu' = \frac{h\nu}{1 + \left(\frac{h\nu}{m_0c^2}\right)(1-\cos\theta)} \qquad m_0c^2 = 0.511 \text{ MeV}$$

$$E_{e^-_{recoil}} = h\nu - h\nu' = h\nu \left(\frac{(h\nu/m_0c^2)(1-\cos\theta)}{1+(h\nu/m_0c^2)(1-\cos\theta)} \right)$$

2 EXTREME CASES

1. GRAZING ANGLE SCATTERING $\theta \cong 0$

$$h\nu' \cong h\nu \quad \& \quad E_{e^-} \cong 0$$

2. HEAD ON COLLISION $\theta = \pi$

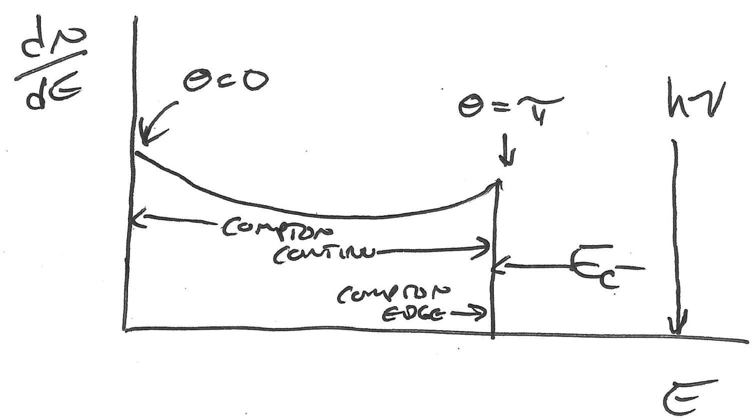
"EXTREME ENERGY THAT CAN BE XFERED TO e^-"

$$h\nu'\Big|_{\theta=\pi} = \frac{h\nu}{1 + \frac{2h\nu}{m_0c^2}}$$

$$E_{e^-}\Big|_{\theta=\pi} = h\nu\left(\frac{2h\nu/m_0c^2}{1+2h\nu/m_0c^2}\right)$$

& EVERYTHING IN BETWEEN.

ELECTRON ENERGY DISTRIBUTION

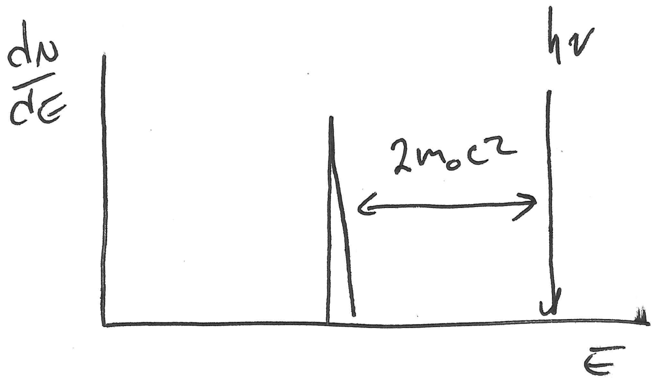


$$E_c = h\nu - E_{e^-}\Big|_{\theta=\pi} = \frac{h\nu}{1+2h\nu/m_0c^2} \qquad h\nu \gg m_0c^2/2$$

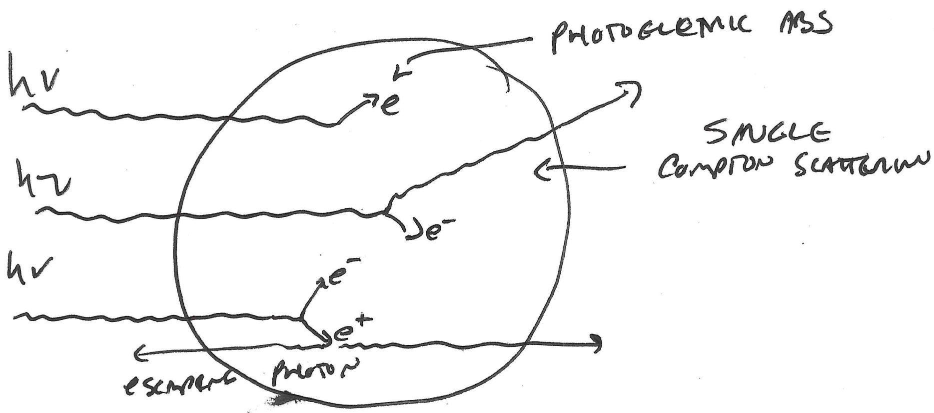
$$E_c \cong \frac{m_0c^2}{2} = 0.256 \text{ MeV}$$

3. PAIR PRODUCTION

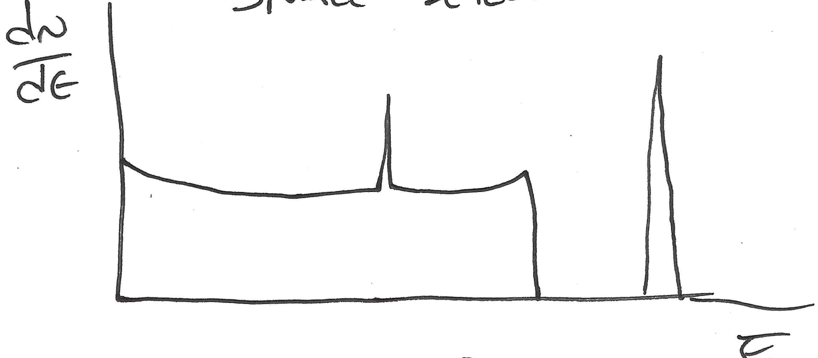
$$E_{e^-} + E_{e^+} = h\nu - 2m_0c^2$$



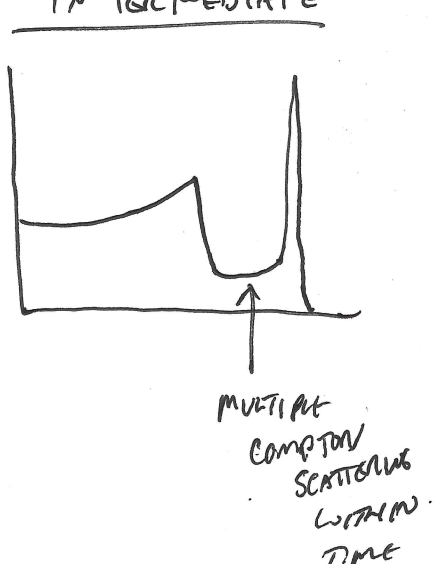
COMBINED EFFECTS DETECTOR RESPONSE.



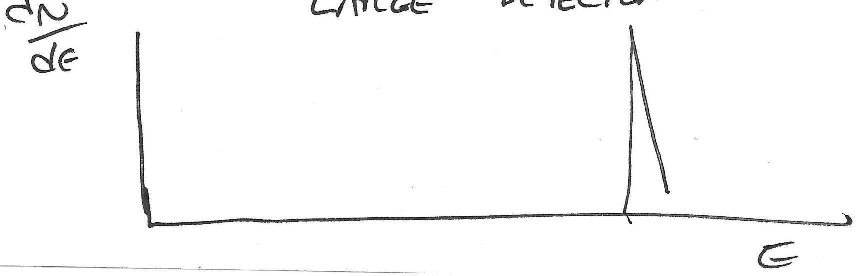
SMALL DETECTOR



INTERMEDIATE



LARGE DETECTOR



RESOLUTION

- CHARGE COLLECTION STATISTICS,
- ELECTRONIC NOISE
- VARIATIONS IN DETECTOR RESPONSE OVER ACTIVE VOLUME
- PM GAIN EVENT TO EVENT
- VARIATION OF LIGHT COLLECTED FROM DIFFERENT REGIONS

STATISTICAL SPREADS ARE SINGLE MOST IMPORTANT CAUSE OF PEAK BROADENING. MOST SIGNIFICANT AT THE POINT OF THE SIGNAL CHAIN WHERE INFORMATION CARRIERS ARE AT A MINIMUM.

SCINT LIGHT → e^- FROM PHOTO CATHODE

EX: 0.5 MeV IS DEPOSITED γ RAY INTO SCINT CRYSTAL,

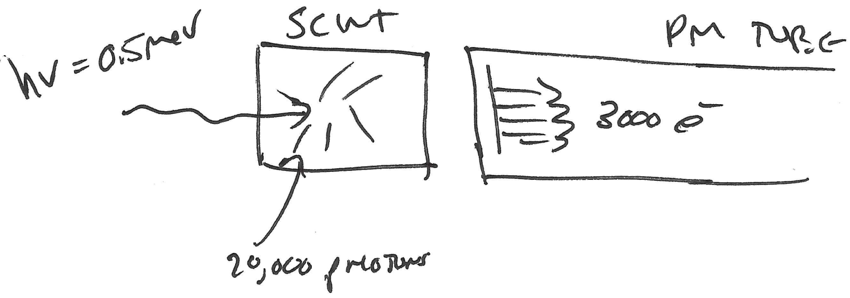
NaI(Tl) SCINT EFF ~ 12%

∴ 60 keV IS CONVERTED INTO VISIBLE LIGHT WITH AVG PHOTON ENERGY OF 3eV

⇒ 20,000 PHOTONS ARE PRODUCED.

ASSUME LOSS AT INTERFACE SO 15,000 PHOTONS HIT PHOTO CATHODE

PMT QE: 20% → 3000 PHOTO ELECTRONS (MINIMUM NUMBER)



$\Longrightarrow$ STN DEV $\sigma = \sqrt{3000}$ 1.8% of MEAN VALUE

ENERGY RESOLUTION IS DEFINED AS FWHM

FWHM IS $2.35 \times \sigma =$

$1.8 \times 2.35 = 4.3\%$

$$R = \frac{FWHM}{PEAK} \times 100\%$$

5% VERY GOOD, 10% TYPICAL