

Radiation Detection Instrumentation Fundamentals

DETECTORS

General Principles of Radiation Detection

In order for the detector to respond at all, the radiation must undergo interaction through one interaction mechanisms. The interaction or stopping time is very small (typically a few nanoseconds in gases or a few picoseconds in solids). In most practical situations, these times are so short that the deposition of the radiation energy can be considered instantaneous

General Principles of Radiation Detection

The net result of the radiation interaction in a wide category of detectors is the appearance of a given amount of electric charge within the detector active volume.

Typically, collection of the charge is accomplished through the imposition of an electric field within the detector, which causes the positive and negative charges created by the radiation to flow in opposite directions.

The time required to fully collect the charge varies greatly from one detector to another. For example, in ion chambers the collection time can be as long as a few milliseconds, whereas in semiconductor diode detectors the time is a few nanoseconds.

These times reflect both the mobility of the charge carriers within the detector active volume and the average distance that must be traveled before arrival at the collection electrodes.

General Principles of Radiation Detection

We can now introduce a fundamental distinction between three general modes of operation of radiation detectors. The three modes are called pulse mode, current mode, and mean square voltage mode.

Pulse mode is easily the most commonly applied of these, but current mode also finds many applications.

MSV mode is limited to some specialized applications that make use of its unique characteristics.

Although the three modes are operationally distinct, they are interrelated through their common dependence on the sequence of current pulses that are the output of our simplified detector model

General Principles of Radiation Detection

In pulse mode operation, the measurement instrumentation is designed to record each individual quantum of radiation that interacts in the detector.

In most common applications, the time integral of each burst of current, or the total charge Q , is recorded since the energy deposited in the detector is directly related to Q .

All detectors used to measure the energy of individual radiation quanta must be operated in pulse mode. Such applications are categorized as radiation spectroscopy and are subject of this lecture.

General Principles of Radiation Detection

Characteristics of Pulse Mod Measurements

- Pulse Height Spectra
- Energy resolution
- Detection Efficiency
- Dead Time

General Principles of Radiation Detection

- Gas-Filled Detectors
- Scintillation Detectors
- Solid State Detectors

Gas-Filled Detectors - Components

- Variable voltage source
- Gas-filled counting chamber
- Two coaxial electrodes well insulated from each other

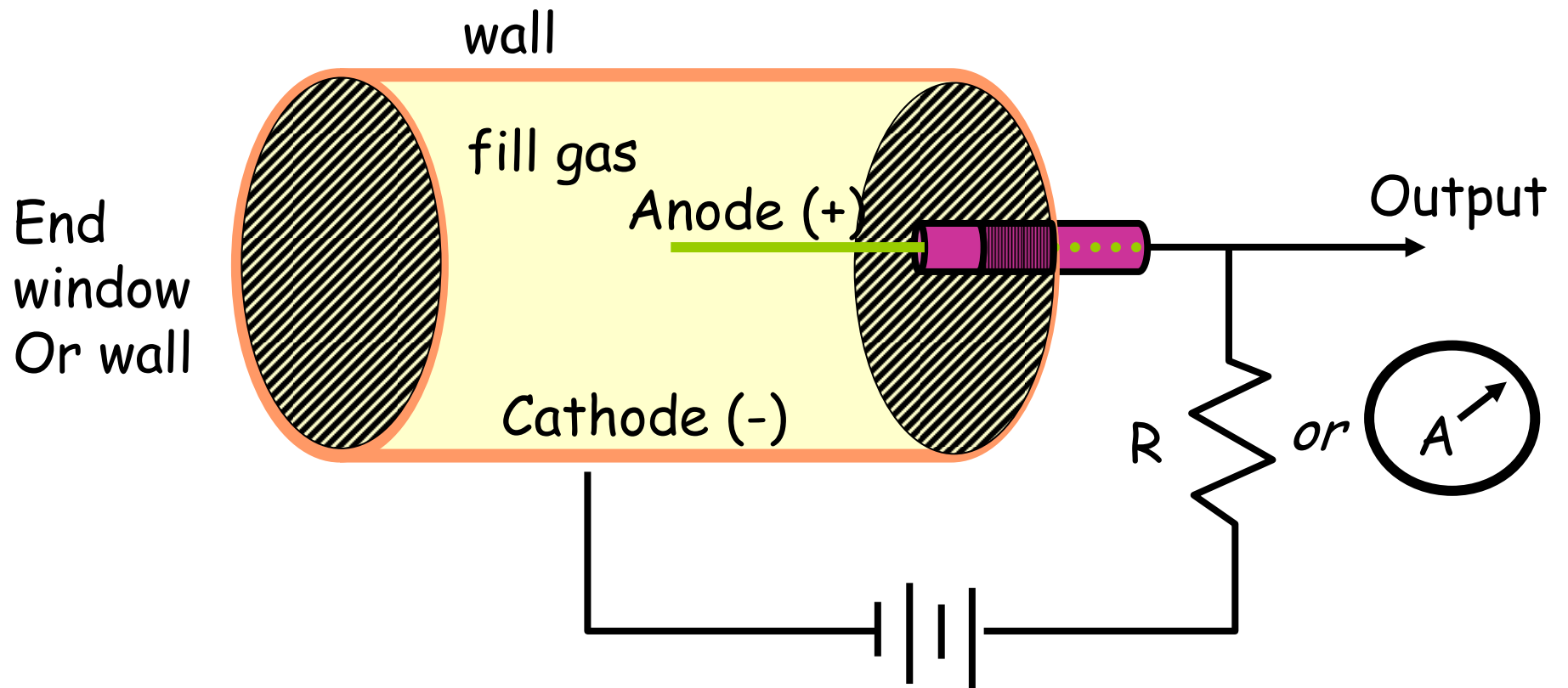
Gas-Filled Detectors

Basic principle

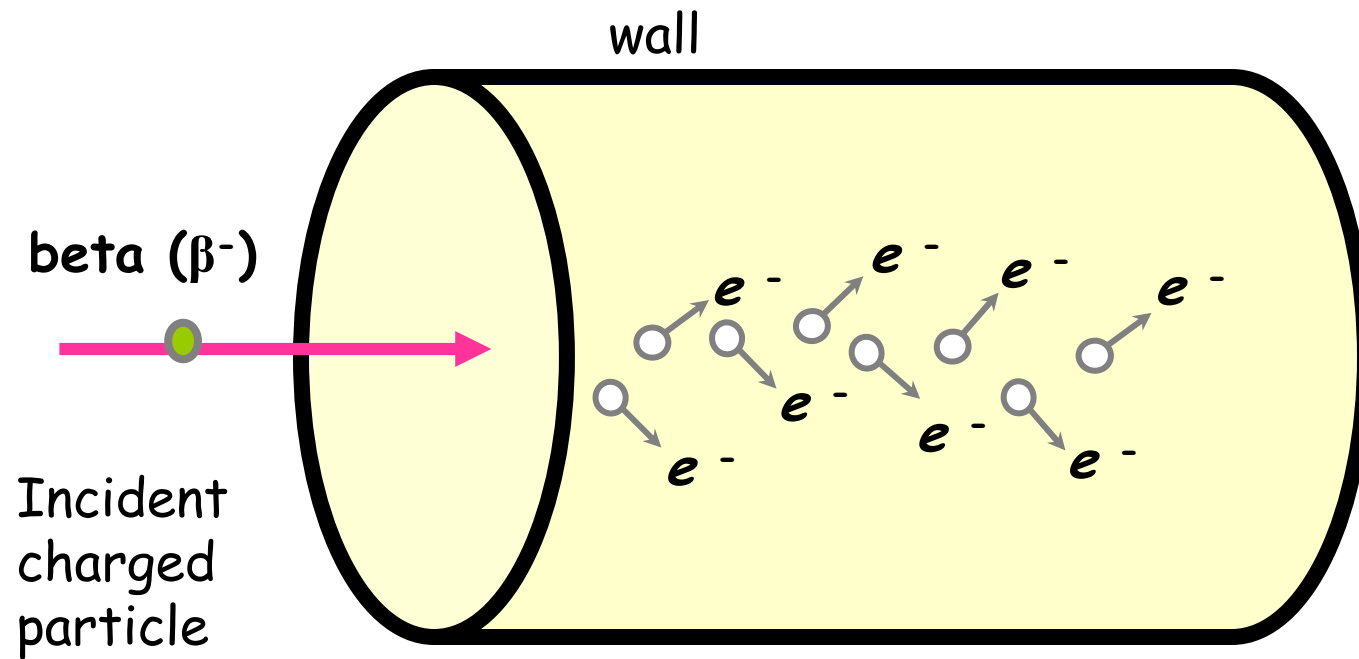
Electron-ions pairs

- produced by radiation in fill gas
- move under influence of electric field
- produce measurable current on electrodes, *or*
- transformed into pulse

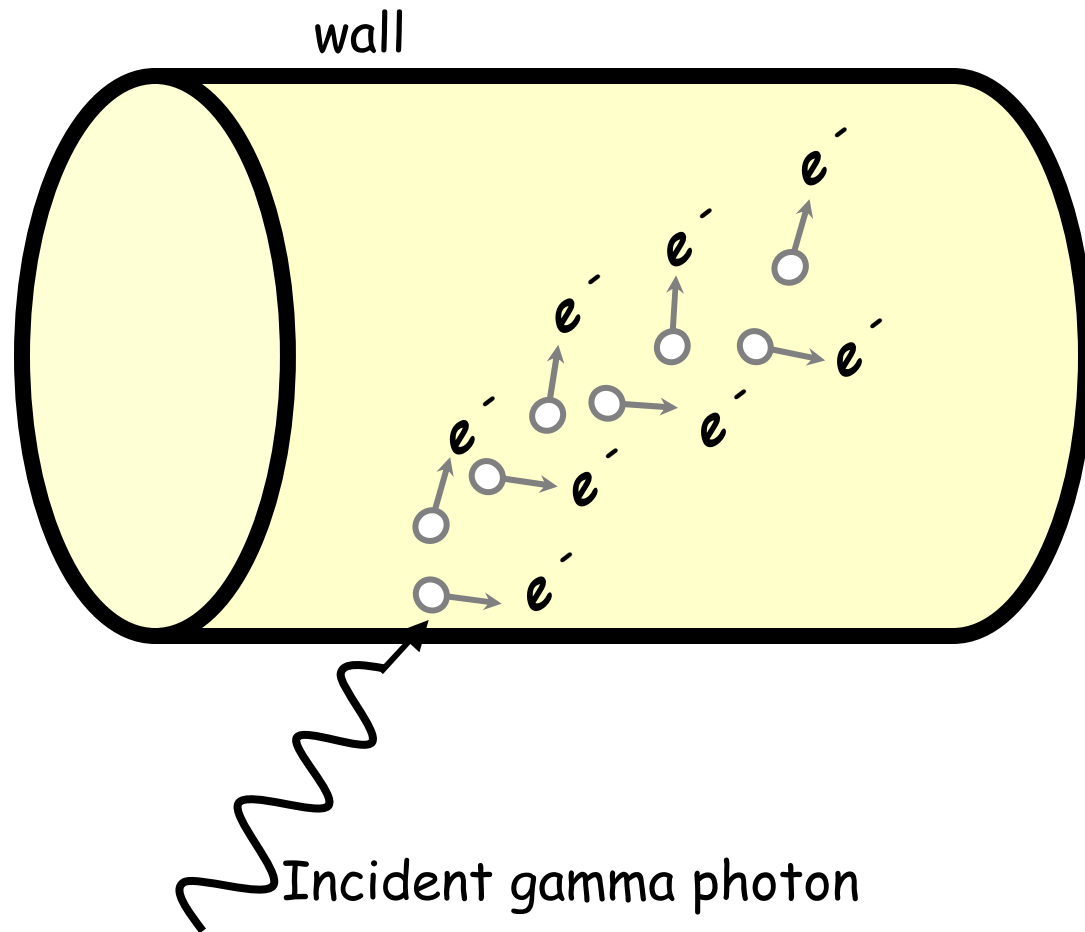
Gas- Filled Detectors - one example



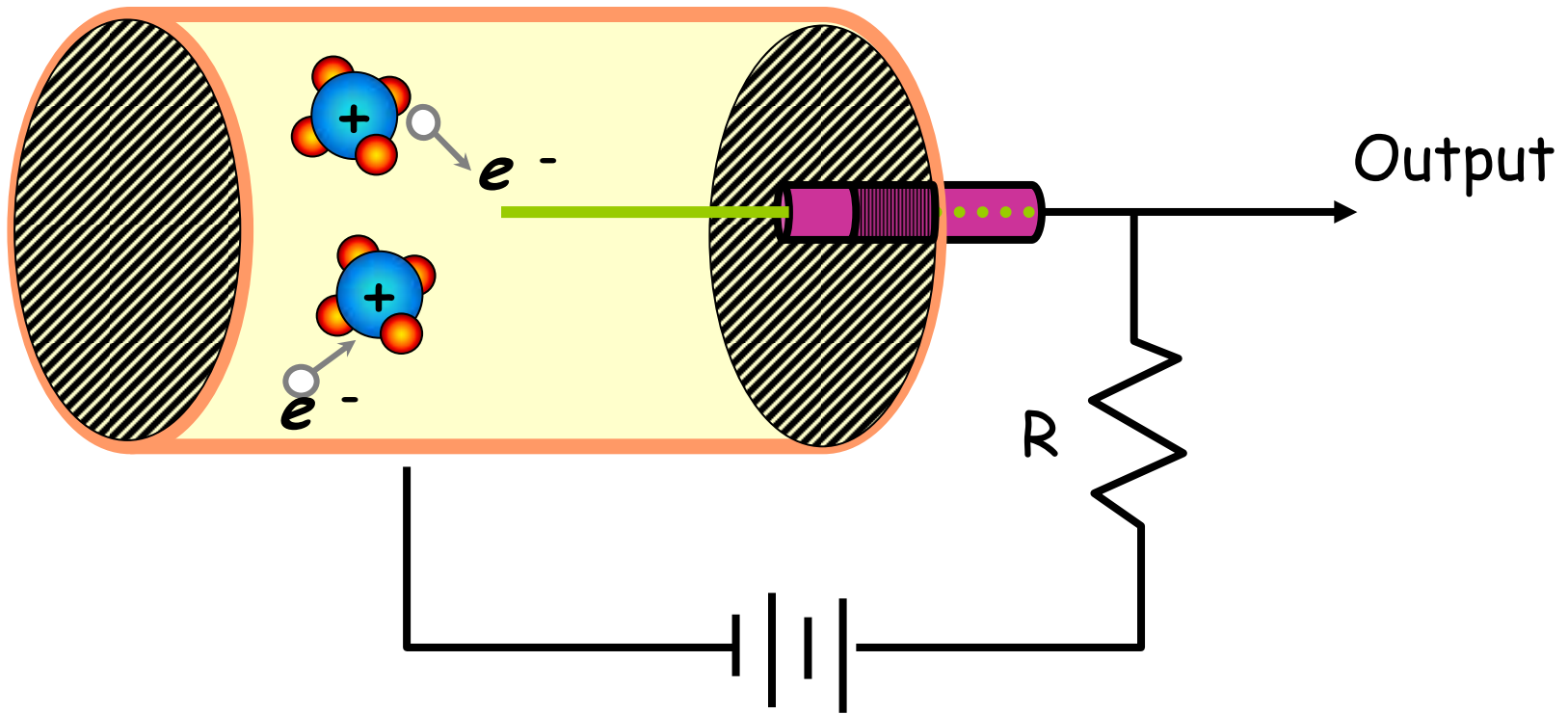
Direct Ionization Process



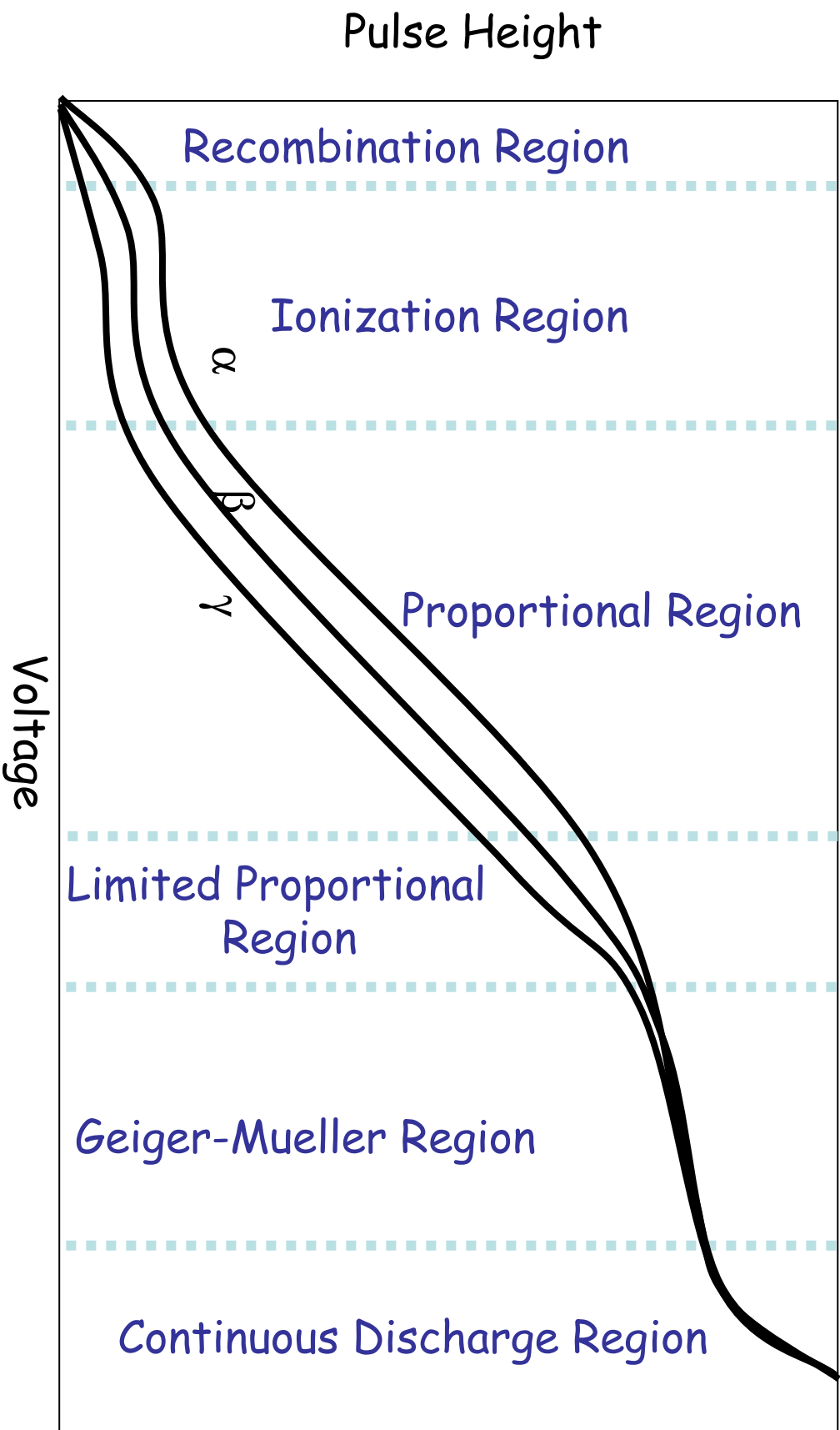
Indirect Ionization Process



Competing Processes - recombination

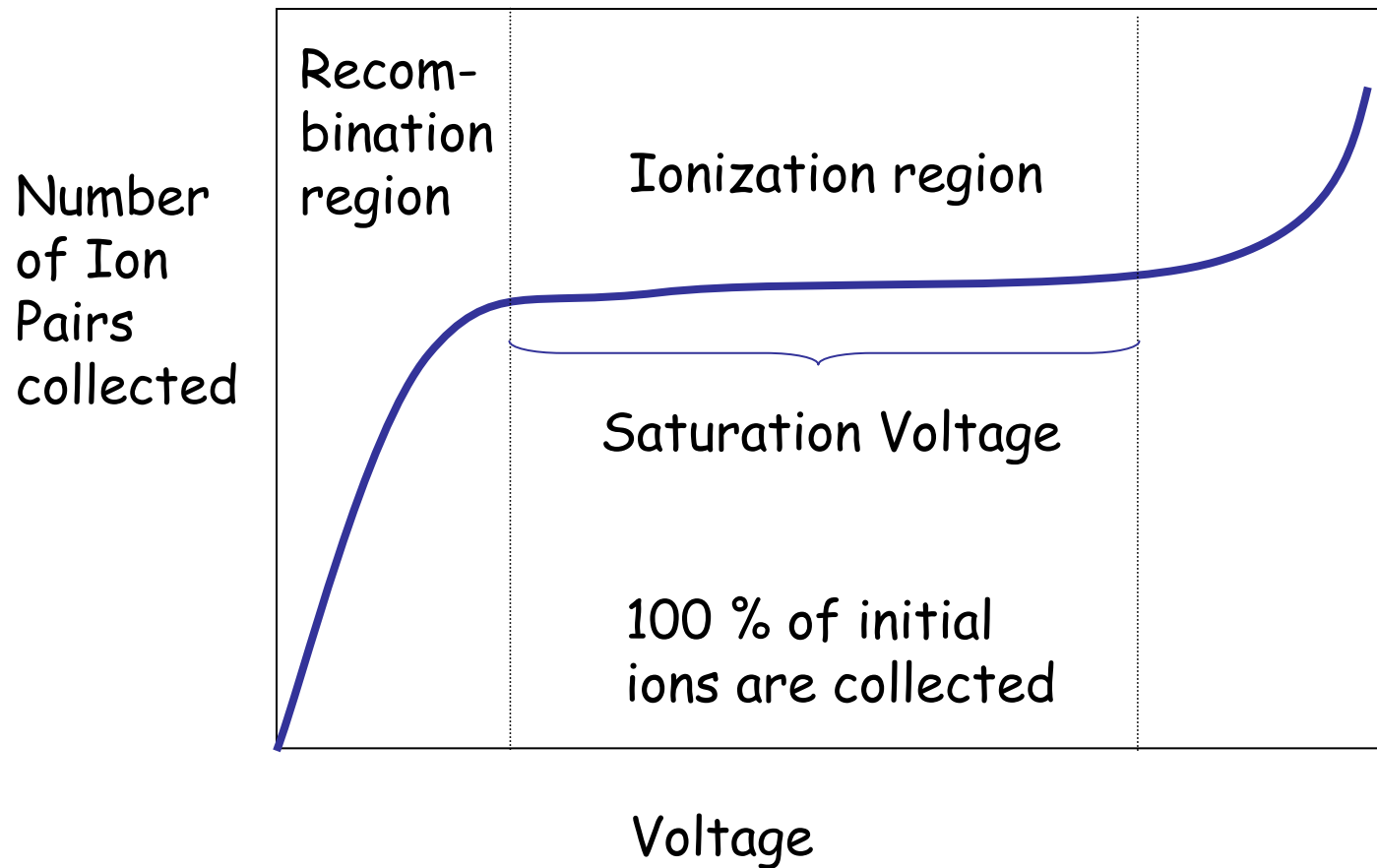


Operating Regions of Gas-Filled Detectors



Ionization Chambers

Voltage versus Ions Collected



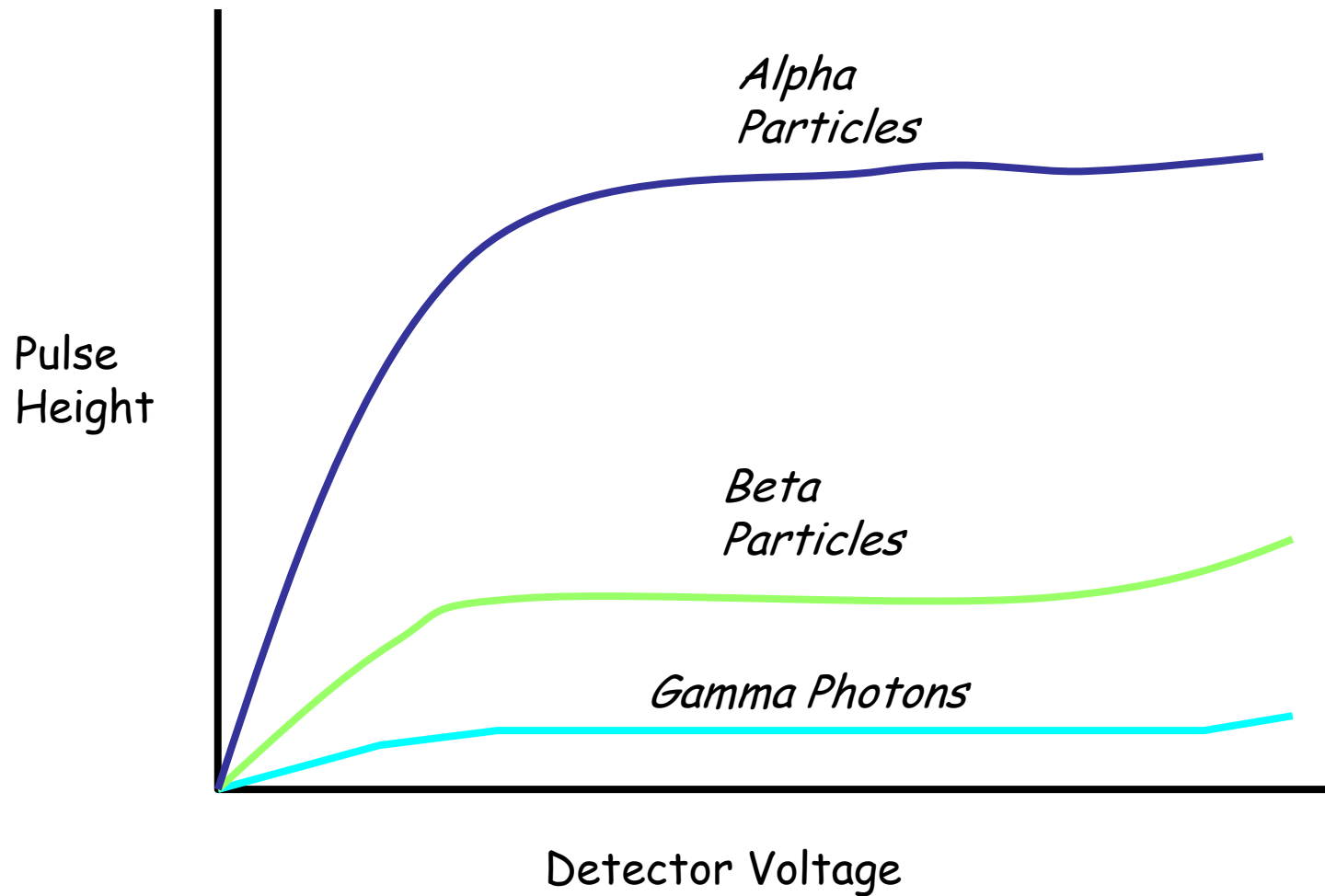
Saturation Current

- The point at which 100% of ions begin to be collected
- All ion chambers operate at a voltage that produces a saturation current
- The region over which the saturation current is produced is called the ionization region
- It levels the voltage range because all charges are already collected and rate of formation is constant

Observed Output: Pulse Height

- Ions collected
- Number of ionizations relate to specific ionization value of radiation
- Gas filled detectors operate in either
 - current mode
 - Output is an average value resulting from detection of many values
 - pulse mode
 - One pulse per particle

Pulse Height Variation



Ionization Region Recap

- Pulse size depends on number of ions produced in detector.
- No multiplication of ions due to secondary ionization (gas amplification is unity)
- Voltage produced $(V) = Q/C$
- Where
 - Q is total charge collected
 - C is capacitance of the ion chamber

Ionization Chambers, continued

- Chamber's construction determines its operating characteristics
- Physical size, geometry, and materials define its ability to maintain a charge
- Operates at a specific voltage
- When operating, the charge collected due to ionizing events is

$$Q = C\Delta V$$

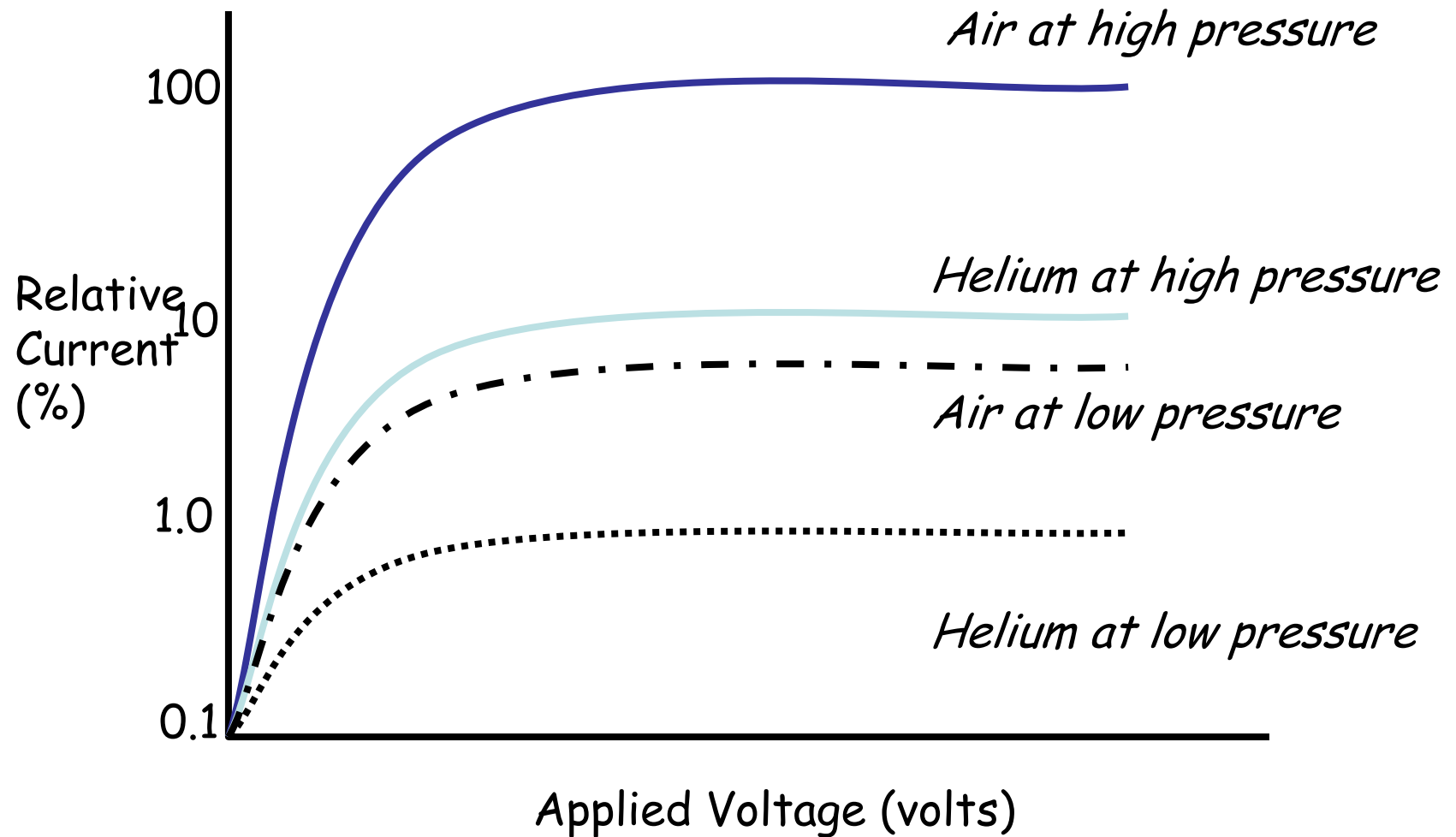
Ionization Chambers, continued

- The number of ions (N) collected can be obtained once the charge is determined:

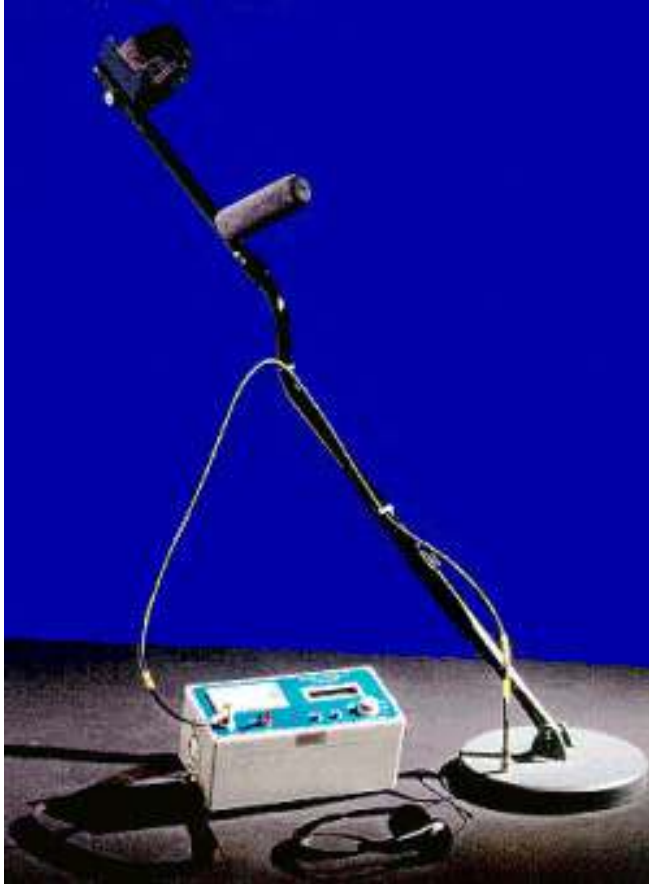
$$N = Q / k$$

- Where k is the electron charge
– $(1.6 \times 10^{-19}\text{C})$

Current vs. Voltage for Fill Gases in a Cylindrical Ion Chamber



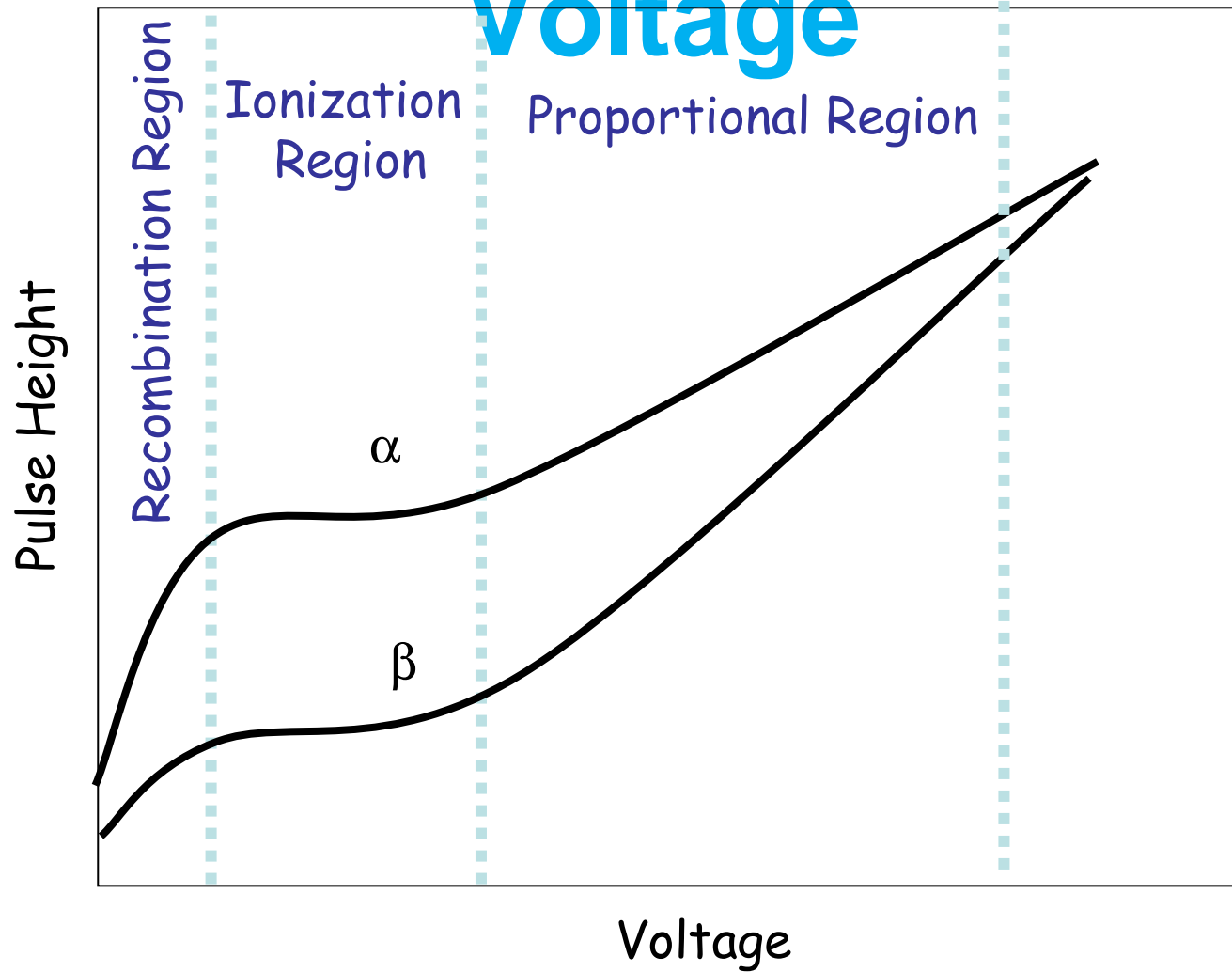
Examples



Proportional Counters

- Operates at higher voltage than ionization chamber
- Initial electrons produced by ionization
 - are accelerated with enough speed to cause additional ionizations
 - cause additional free electrons
 - produces more electrons than initial event
- Process is termed: gas amplification

Pulse-Height Versus Voltage



Selection of the Operating Voltage

- For charged radiations such as alpha or beta particles, a signal pulse will be produced for every particle that deposits a significant amount of energy in the fill gas.
- The proportional counters are seldom operated in a mode that is sensitive to single avalanches in order to prevent nonlinearities for larger pulses due to space charge effects.

Fill gas

- selected to enhance gas multiplication
- no appreciable electron attachment
- most common is P-10 (90% Argon and 10% methane)

Distinguishing Alpha & Beta

- Proportional counters
 - can distinguish between different radiation types
 - specifically alpha and beta-gamma
- Differential detection capability
 - due to size of pulses produced by initial ionizing events
 - requires voltage setting in range of 900 to 1,300 volts
 - alpha pulses above discriminator
 - beta/gamma pulses too small

Alpha Counting

- For alpha particle sources, proportional counters can record easily each particle that enters the active volume with virtually 100% efficiency.
- Absolute measurements of alpha source activity are therefore relatively straightforward and involve evaluation of the effective solid angle subtended by the counter active volume.
- Windowless

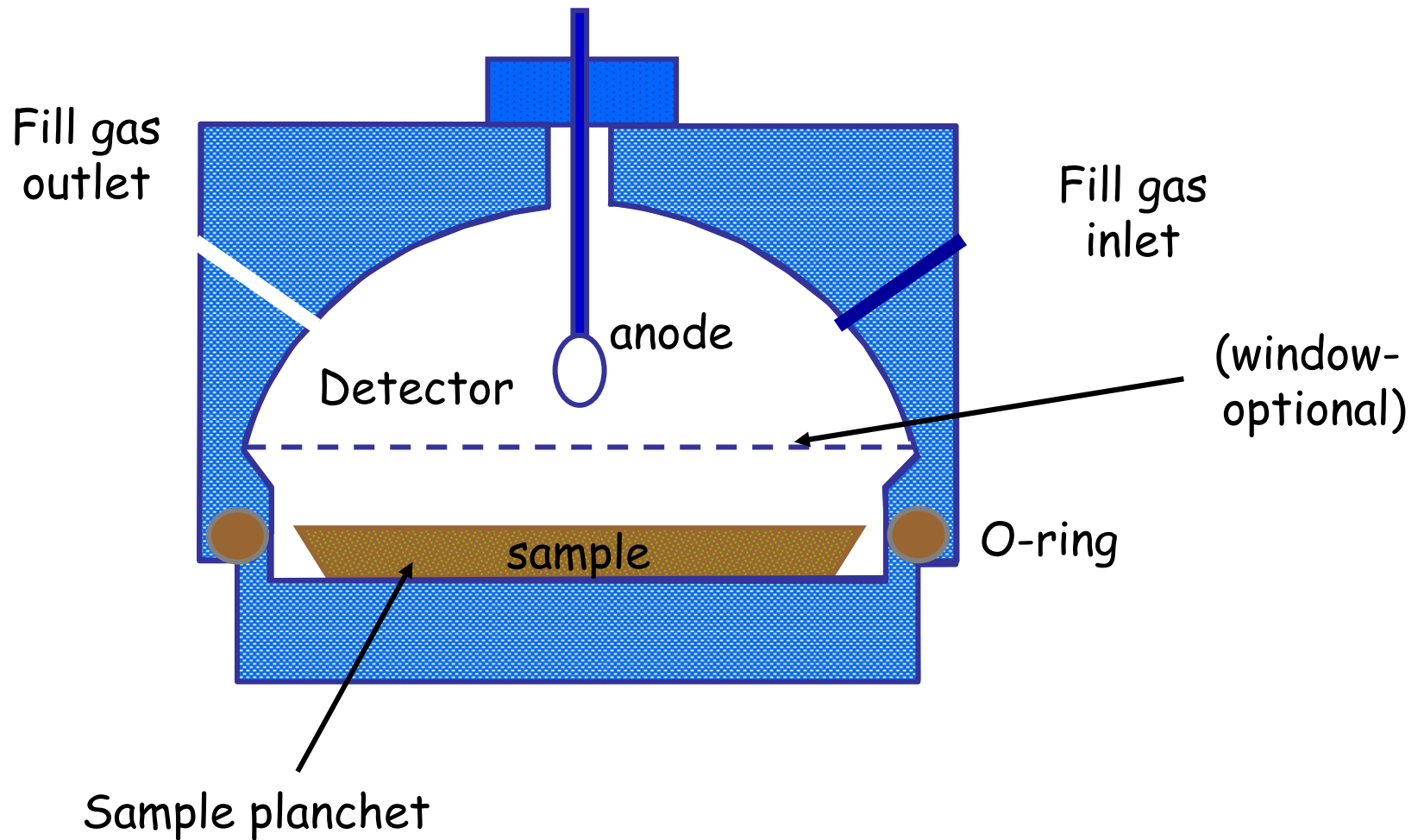
Beta Counting

- For beta particles of typical energies, the particle range greatly exceeds the chamber dimensions.
- The numbers of ion pairs formed in the gas is then proportional to only that small fraction of the particle energy lost in the gas before reaching the opposite wall

Gas-Flow Proportional Counter



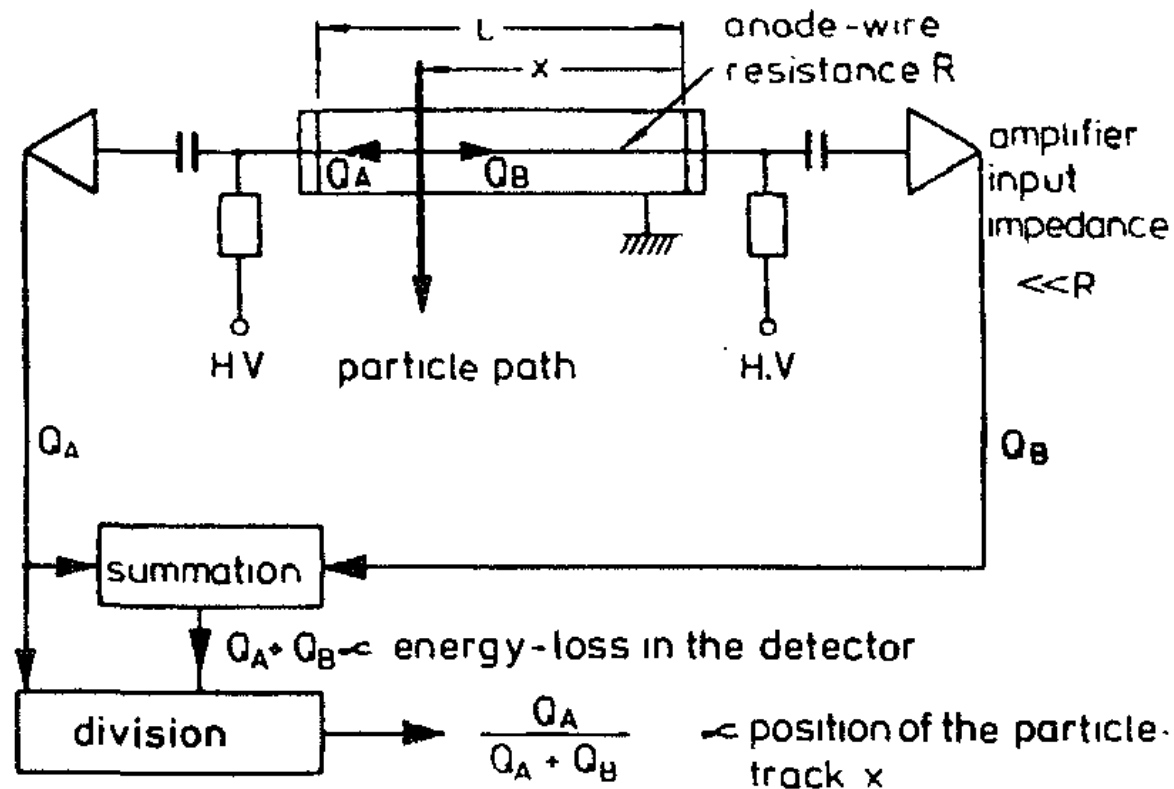
Gas-Flow Proportional Counter





Variants of the Proportional Counter Design

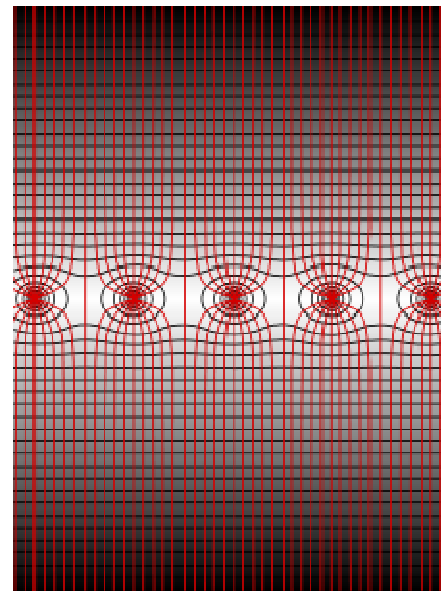
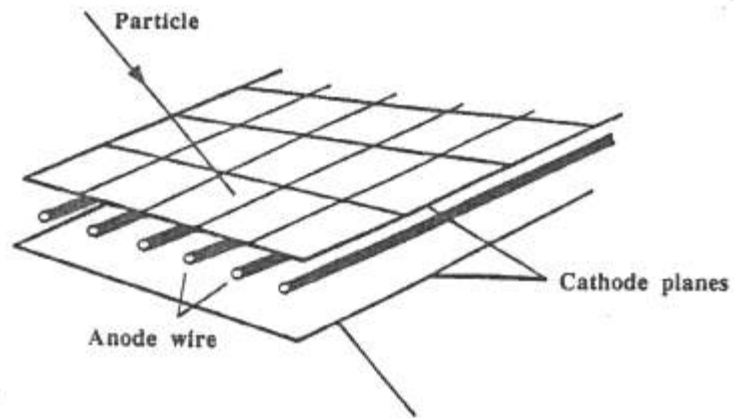
Position-Sensitive Proportional Counters



Multiwire Proportional Counters

- In some situations, it is advantageous to provide more than one anode wire within a proportional counter.
- Detectors with very large surface area can be constructed by placing a grid of anode wires between two large flat planes that serves as cathodes on either side of the counter

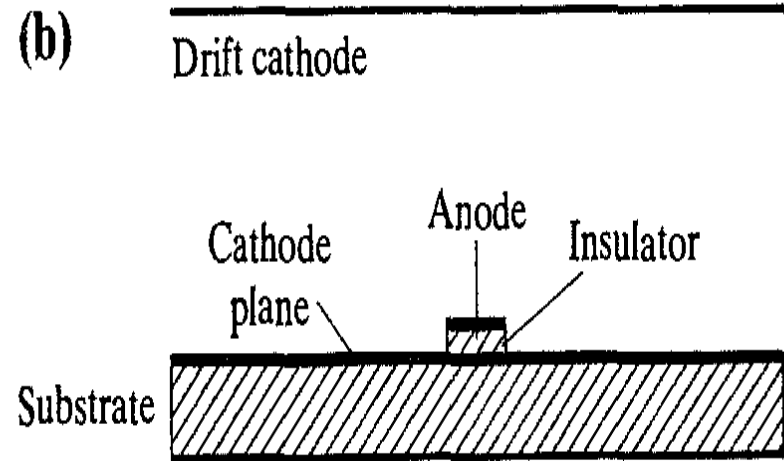
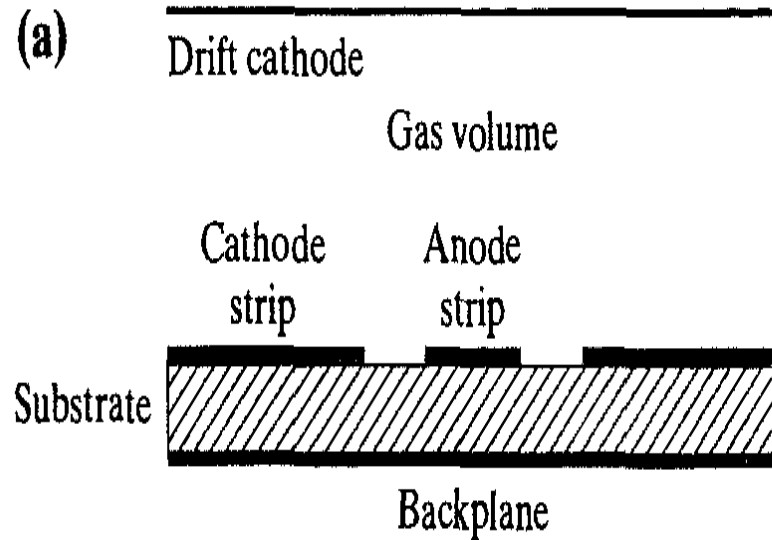
Multiwire Proportional Counters



Microstrip Gas Chamber

- On insulating substrate , metallic electrodes are formed by etching techniques.
- The anode structures are kept quite narrow (typically 10 microns) so that the same type of concentration of the electric field that occurs around the wire is realized near the surface of the anode strip.
- Thus avalanches will be formed as electrons are drawn in to the anode strip surface

Microstrip Gas Chamber



Geiger Mueller Detectors

- Operate at voltages above proportional detectors
- Each primary ionization
 - produces a complete avalanche of ions throughout the detector volume
 - called a Townsend Avalanche
 - continues until maximum number of ion pairs are produced
 - avalanche may be propagated by photoelectrons
 - quenching is used to prevent process

Geiger Mueller Detectors

- A typical pulse from Geiger tube represents a large amount of collected charge, about 10^{10} ion pairs being formed in the discharge.
- No proportional relationship between energy of incident radiation and number of ionizations detected
- A level pulse height occurs throughout the entire voltage range

Geiger Mueller Detectors

Fill Gases

- Noble gases with helium and argon the most popular choices.
- Even trace amounts of gases that forms negative ions (such as oxygen) must be avoided
- Operate at atmospheric pressure or tenths of an atmospheric pressure.
- Operating voltages up to 2000 V.

Geiger Mueller Detectors

Quenching

- The problem of multiple pulsing is severe in Geiger tubes.
- Internal quenching is accomplished by adding a second component called the quenching gas to the primary fill gas, in proportion of 5-10%.
- Large organic molecules like ethyl alcohol and ethyl formate prevent the reemission of free electrons from the cathode.





Advantages/Disadvantages of Gas-Filled Detectors

- Ion Chamber: simple, accurate, wide range, sensitivity is function of chamber size, no dead time
- Proportional Counter: discriminate hi/lo Linear Energy Transfer, higher sensitivity than ion chamber
- GM Tube: cheap, little/no amplification, thin window for low energy; limited life

Issues with Gas Filled Detectors: Dead Time

- Minimum time at which detector recovers enough to start another avalanche (pulse)
- The dead time may be set by:
 - limiting processes in the detector, or
 - associated electronics
- “Dead time losses”
 - can become severe in high counting rates
 - corrections must be made to measurements

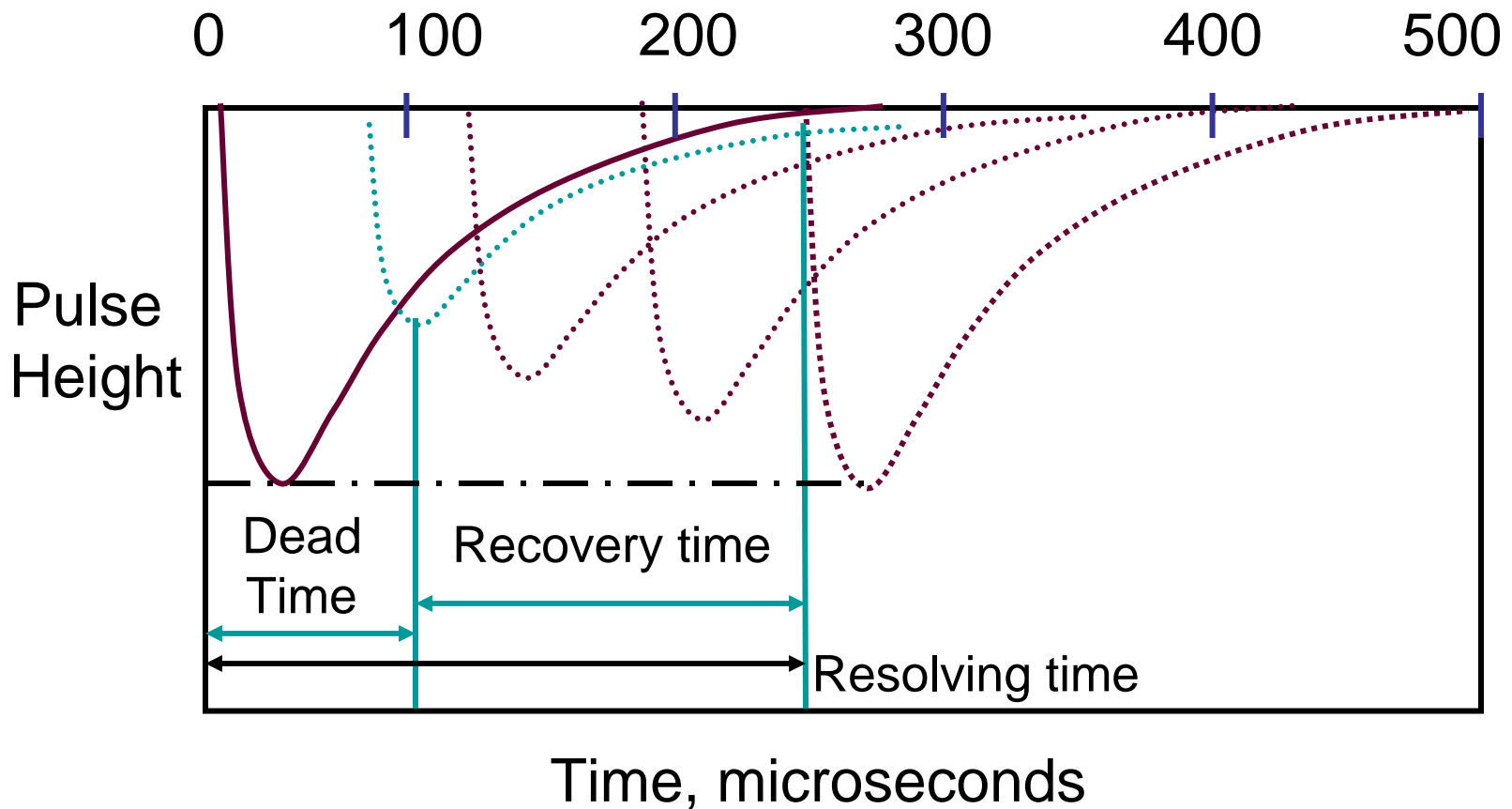
Issues with Gas Filled Detectors: Recovery Time

- Time interval between dead time and full recovery
- Recovery Time = Resolving time - dead time

Issues with Gas Filled Detectors: Resolving Time

- Minimum time interval that must elapse after detection of an ionizing particle before a second particle can be detected.

Relationship among dead time, recovery time, and resolving time



SCINTILLATION DETECTORS

SCINTILLATION DETECTORS

The ideal scintillation material should possess the following properties:

1. It should convert the kinetic energy of charged particles into detectable light with a high scintillation efficiency.
2. This conversion should be linear—the light yield should be proportional to deposited energy over as wide a range as possible.
3. The medium should be transparent to the wavelength of its own emission for good light collection.
4. The decay time of the induced luminescence should be short so that fast signal pulses can be generated.
5. The material should be of good optical quality and subject to manufacture in sizes large enough to be of interest as a practical detector.
6. Its index of refraction should be near that of glass (~ 1.5) to permit efficient coupling of the scintillation light to a photomultiplier tube or other light sensor.

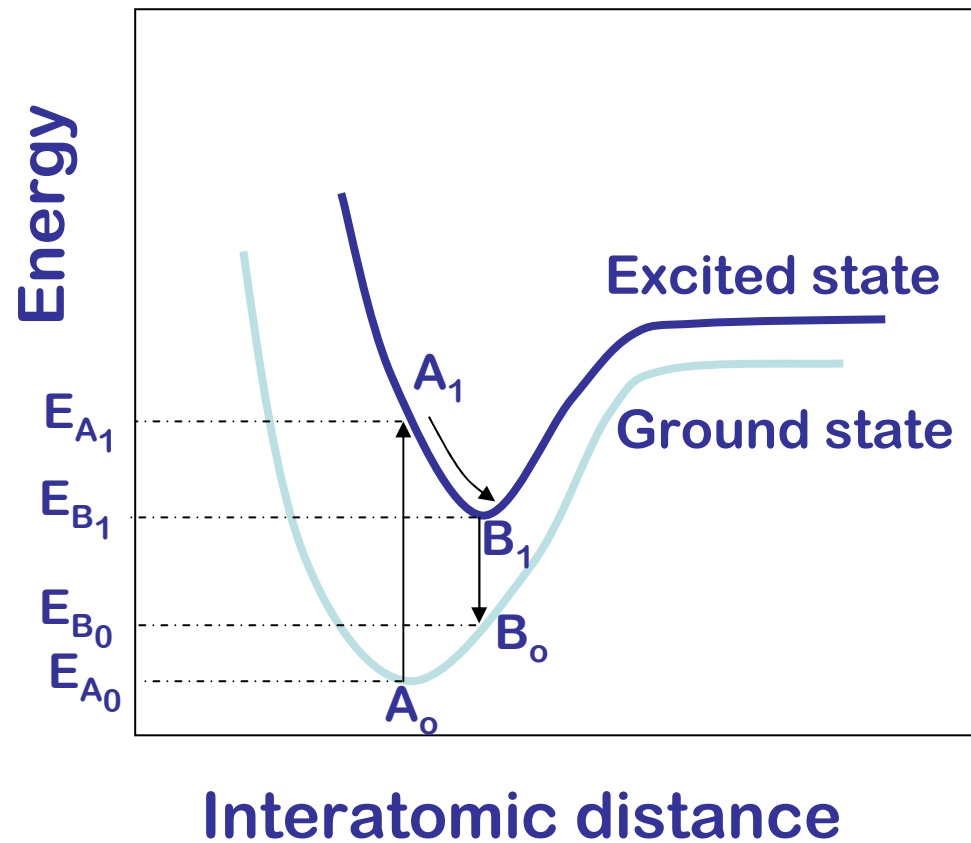
Scintillators

- Emit light when irradiated
 - promptly ($<10^{-8}$ s)
 - fluorescence
 - delayed ($>10^{-8}$ s)
 - phosphorescence
- Can be
 - liquid
 - solid
 - gas
 - organic
 - inorganic

Scintillators

- The fluorescence process in organics arises from transitions in the energy level structure of a single molecule and therefore can be observed from a given molecular species independent of its physical state
- In contrast, crystalline inorganic scintillators require a regular crystalline lattice as basic for the scintillation process.

Basis of Scintillation - Energy Structure in a Molecule

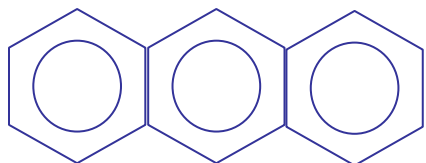


Organic Scintillators

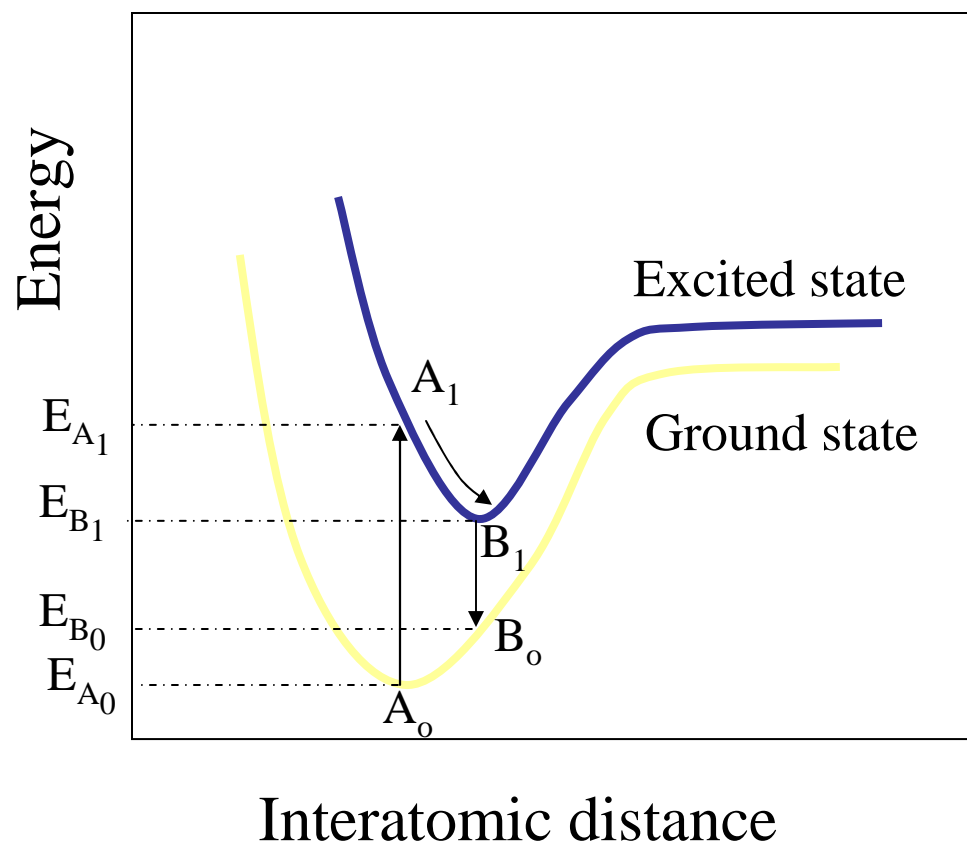
- Examples
- Differences



Toluene



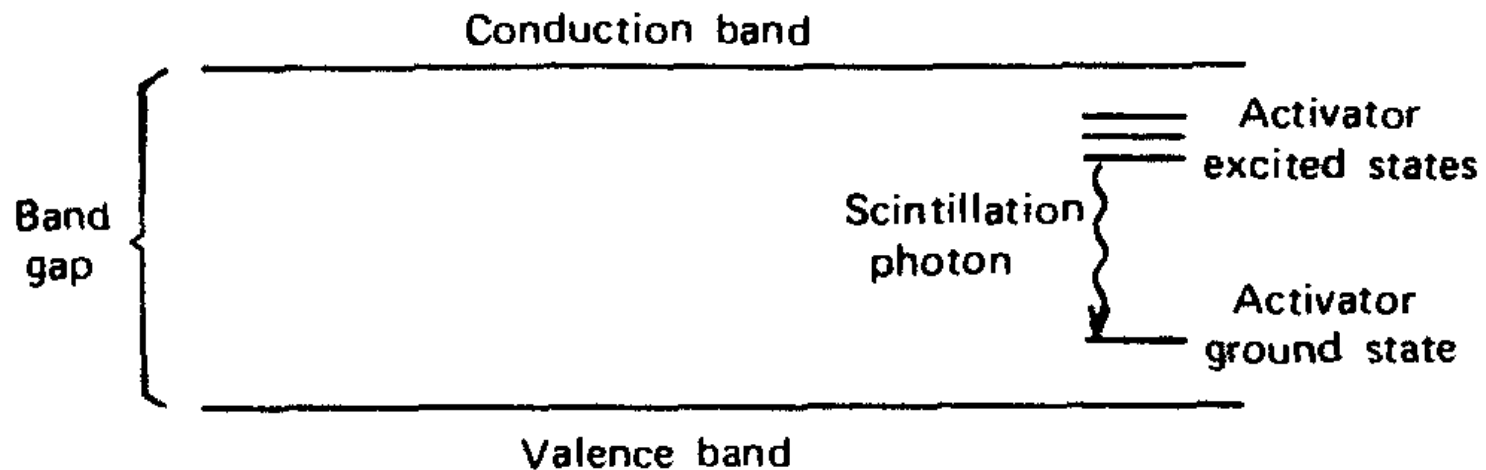
Anthracene



Inorganic (Crystal) Scintillators

- Most are crystals of alkali metals (iodides)
 - NaI(Tl)
 - CsI(Tl)
 - CaI(Na)
 - LiI(Eu)
 - CaF₂(Eu)
- Impurity in trace amounts
 - “activator” causes luminescence
 - e.g., (Eu) is 10⁻³ of crystal

Energy band structure of an activated crystalline scintillator



Scintillator efficiency

- One electron-pair creation requires in, NaI, aprox. 20 eV charged particle energy lost (three times the gap band).
- For 1 MeV energy deposited in scintillator aprox 5×10^4 electron-holes are created.
- For NaI(Tl) the absolute scintillation efficiency is about 12% which results in 1.2×10^5 eV in light energy or 4×10^4 photons with average energy of 3 eV.

Selecting Scintillators - Density and Atomic number

- Efficient detection of gamma-rays requires material with a high density and high Z
- Inorganic scintillation crystals meet the requirements of stopping power and optical transparency,
 - Densities range from roughly 3 to 9 g/cm³
 - Very suitable to absorb gamma rays.
 - Materials with high Z-values are used for spectroscopy at high energies (>1 MeV).

Commonly Used Scintillators

Material	Density [g/cm ³]	Emission Max [nm]	Decay Constant (1)	Refractive Index (2)	Conversion Efficiency (3)	Hygroscopic
NaI(Tl)	3.67	415	0.23 μ s	1.85	100	yes
CsI(Tl)	4.51	550	0.6/3.4 μ s	1.79	45	no
CsI(Na)	4.51	420	0.63 μ s	1.84	85	slightly
CsI undoped	4.51	315	16 ns	1.95	4 - 6	no
CaF₂ (Eu)	3.18	435	0.84 μ s	1.47	50	no
⁶ LiI (Eu)	4.08	470	1.4 μ s	1.96	35	yes
⁶ Li - glass	2.6	390 - 430	60 ns	1.56	4 - 6	no
CsF	4.64	390	3 - 5 ns	1.48	5 - 7	yes

(1) Effective average decay time For γ -rays.

(2) At the wavelength of the emission maximum.

(3) Relative scintillation signal at room temperature for γ -rays when coupled to a photomultiplier tube with a Bi-Alkalai photocathode.

Commonly Used Scintillators

Material	Density [g/cm ³]	Emission Maximum [nm]	Decay Constant (1)	Refractive Index (2)	Conversion Efficiency (3)	Hygroscopic
BaF ₂	4.88	315 220	0.63 μs 0.8 ns	1.50 1.54	16 5	no
YAP (Ce)	5.55	350	27 ns	1.94	35 - 40	no
GSO (Ce)	6.71	440	30 - 60 ns	1.85	20 - 25	no
BGO	7.13	480	0.3 μs	2.15	15 - 20	no
CdWO ₄	7.90	470 / 540	20 / 5 μs	2.3	25 - 30	no
Plastics	1.03	375 - 600	1 - 3 μs	1.58	25 - 30	no

(1) Effective average decay time For γ -rays.

(2) At the wavelength of the emission maximum.

(3) Relative scintillation signal at room temperature for γ -rays when coupled to a photomultiplier tube with a Bi-Alkali photocathode.

Mechanical and Optical Properties

- NaI(Tl) is one of the most important scintillants.
 - Hygroscopic
 - Can only be used in hermetically sealed metal containers
- Some scintillation crystals may easily crack or cleave under mechanical pressure
- CsI is “plastic” and will deform.
- For high resolution spectroscopy, NaI(Tl), or CsI(Na) (high light output) are normally used.
- For high energy physics applications, the use of bismuth germanate $\text{Bi}_4\text{Ge}_3\text{O}_{12}$ (BGO) crystals (high density and Z) improves the lateral confinement of the shower.
- For the detection of beta-particles, $\text{CaF}_2(\text{Eu})$ can be used instead of plastic scintillators (higher density).

Decay time

- Scintillation light pulses (flashes) are usually characterized by a fast increase of the intensity in time (pulse rise time) followed by an exponential decrease.
- *Decay time* of a scintillator is defined by the time after which the intensity of the light pulse has returned to $1/e$ of its maximum value.
- Most scintillators are characterized by more than one decay time and usually, the effective average decay time is given
- The decay time is of importance for fast counting and/or timing applications

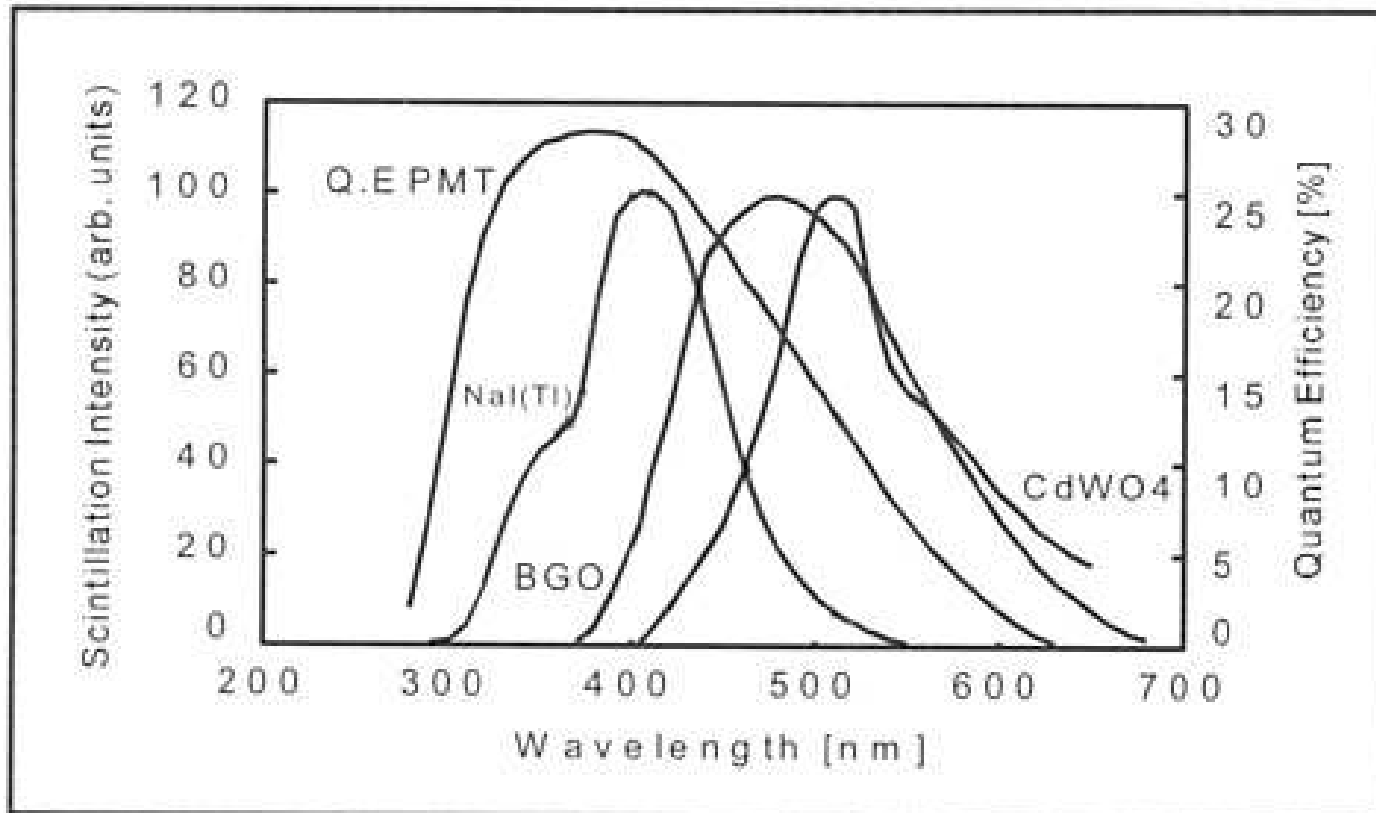
Afterglow

- Defined as the fraction of scintillation light still present for a certain time after the X-ray excitation stops.
 - Originates from the presence of millisecond to even hour long decay time components.
 - Can be as high as a few % after 3 ms in most halide scintillation crystals .
 - CsI(Tl) long duration afterglow can be a problem for many applications.
 - Afterglow in halides is believed to be intrinsic and correlated to certain lattice defects.
- BGO and Cadmium Tungstate (CdWO_4) crystals are examples of low afterglow scintillation materials

Emission Spectra of Scintillation Crystals

- Each scintillation material has characteristic emission spectrum.
- Spectrum shape is sometimes dependent on the type of excitation (photons / particles).
- Emission spectrum is important when choosing the optimum readout device (PMT /photodiode) and the required window material.
- Emission spectrum of some common scintillation materials shown in next two slides.

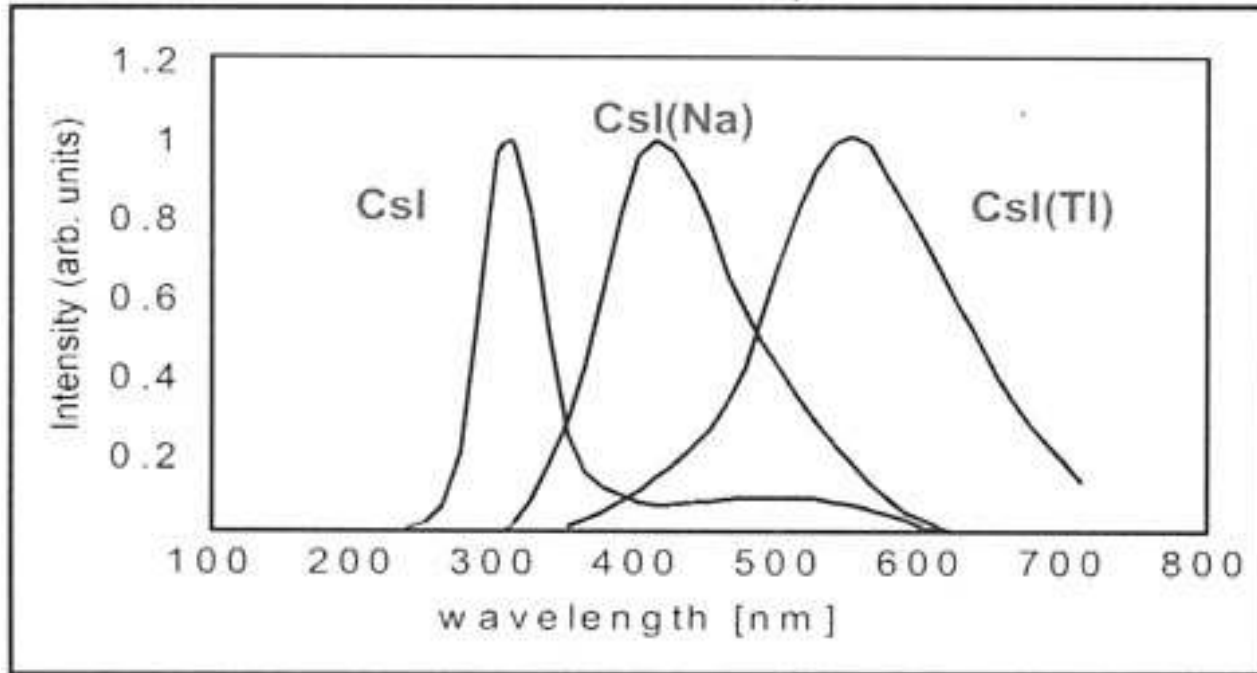
Emission Spectra of Scintillators



Emission spectra of NaI(Tl), BGO and CdWO₄, scaled on maximum emission intensity.

Emission Spectra of Scintillators

A typical human eye will respond to wavelengths from
about 390 to 700 nm.

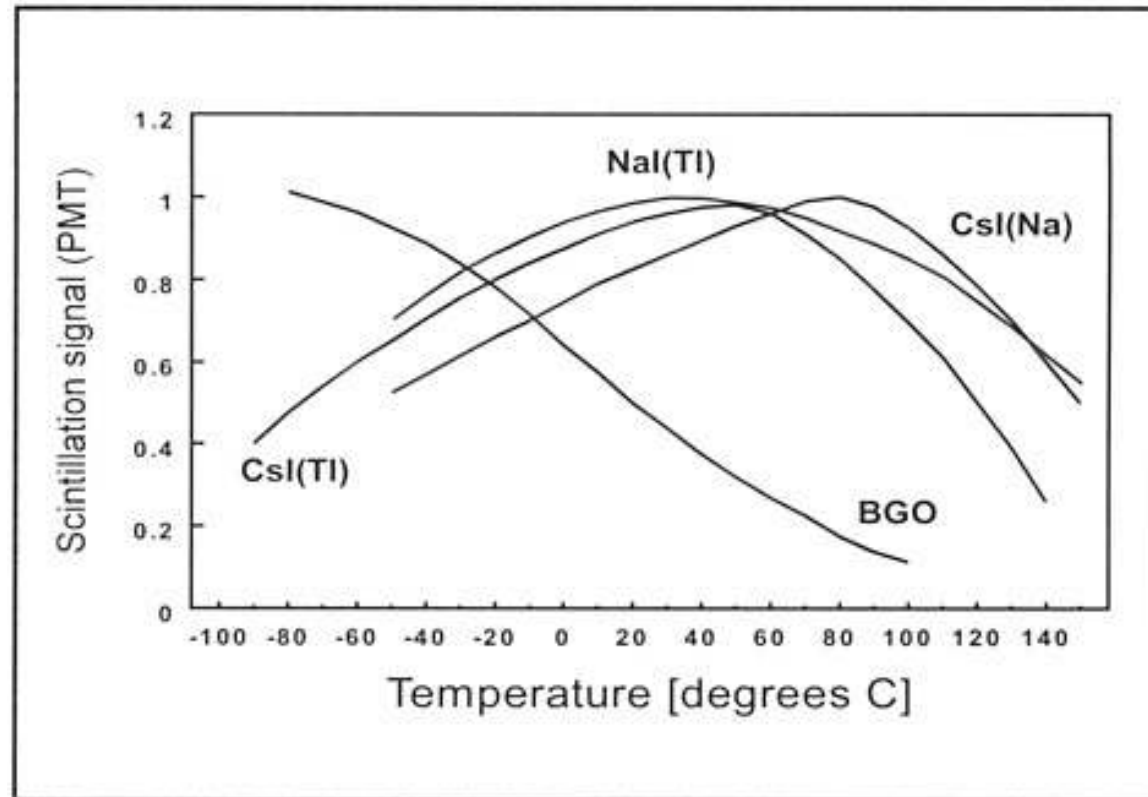


Emission spectra of CsI, CsI(Na) and CsI(Tl) scaled on maximum emission intensity. Also a typical quantum efficiency curve of a bialkali photocathode is shown.

Temperature Influence on the Scintillation Response

- Light output (photons per MeV gamma) of most scintillators is a function of temperature.
 - Radiative transitions, responsible for the production of scintillation light compete with non-radiative transitions (no light production).
 - In most light output is quenched (decreased) at higher temperatures.
 - An exception is the fast component of BaF_2 where intensity is essentially temperature independent.

Temperature Influence on the Scintillation Response



Temperature dependence of the scintillation yield of NaI(Tl), CsI(Na), CsI(Tl) and BGO.

Scintillators - Neutron Detection

- Neutrons do not produce ionization directly in scintillation crystals
- Can be detected through their interaction with the nuclei of a suitable element.
 - ${}^6\text{LiI}(\text{Eu})$ crystal -neutrons interact with ${}^6\text{Li}$ nuclei to produce an alpha particle and ${}^3\text{H}$ which both produce scintillation light that can be detected.
 - Enriched ${}^6\text{Li}$ containing glasses doped with Ce as activator can also be used.

Neutron Detection

Table 7: Some Reactions Useful for Slow-Neutron Detection

reaction*	Q-value (MeV)	cross section (in barns) for thermal (0.025 eV) neutrons
$^{10}\text{B} + \text{n} \rightarrow ^7\text{Li} + \alpha$	2.31	3,840
$^6\text{Li} + \text{n} \rightarrow ^3\text{H} + \alpha$	4.78	940
$^3\text{He} + \text{n} \rightarrow ^3\text{H} + \text{p}$	0.764	5,330
$^{235}\text{U} + \text{n} \rightarrow \text{X} + \text{Y}$ (fission fragments)	~200	575

*n represents a neutron, p a proton, and α an alpha particle.

Neutron Detection

- Conventional neutron meters surround a thermal neutron detector with a large and heavy (20 lb) polyethylene neutron moderator.
- Other meters utilizes multiple windows formed of a fast neutron scintillator (ZnS in an epoxy matrix), with both a thermal neutron detector and a photomultiplier tube.

Radiation Damage in Scintillators

- Radiation damage results in change in scintillation characteristics caused by prolonged exposure to intense radiation.
- Manifests as decrease of optical transmission of a crystal
 - decreased pulse height
 - deterioration of the energy resolution
- Radiation damage other than activation may be partially reversible; i.e. the absorption bands disappear slowly in time.

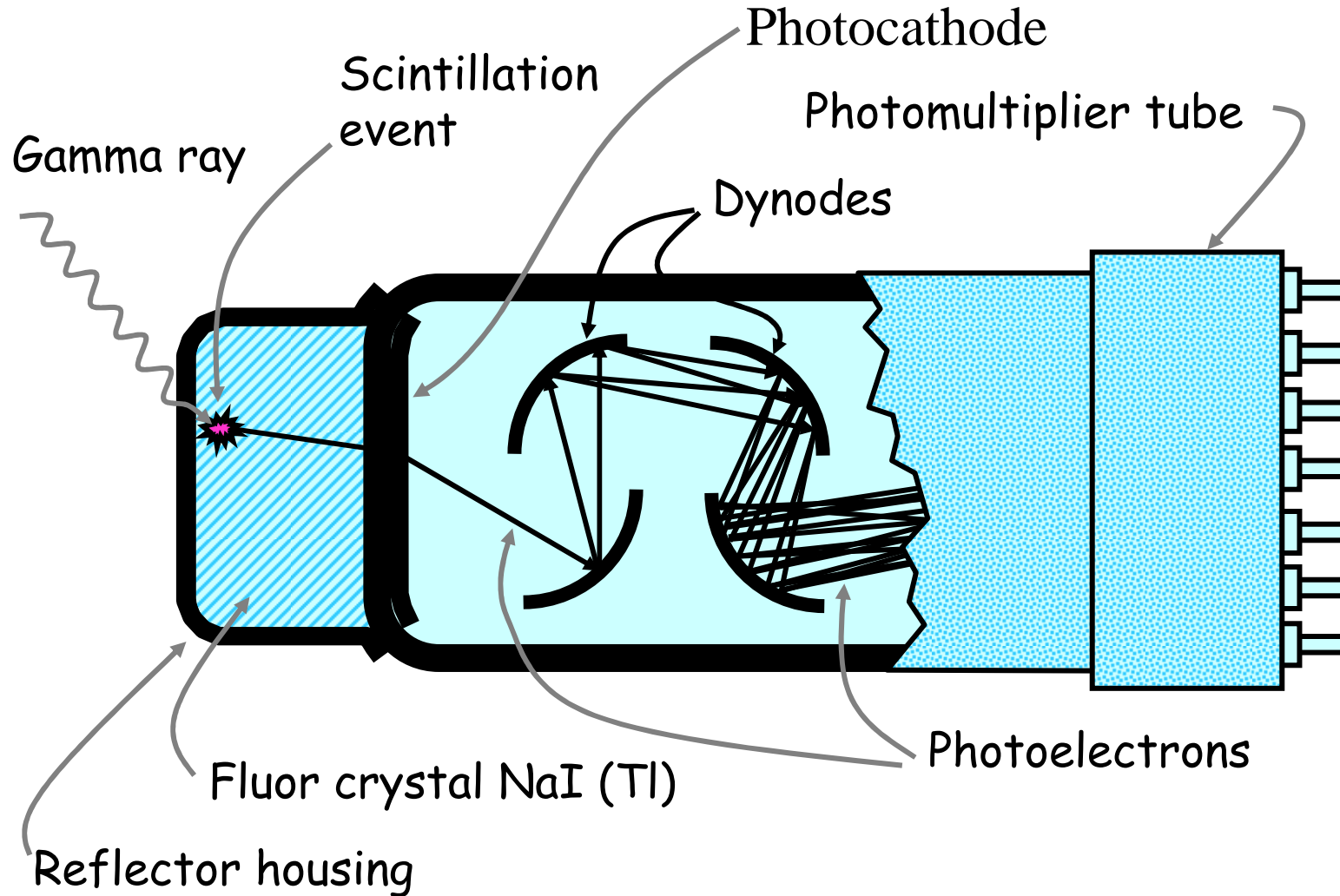
Radiation Damage in Scintillators

- Doped alkali halide scintillators such as NaI(Tl) and CsI(Tl) are rather susceptible to radiation damage.
- All known scintillation materials show more or less damage when exposed to large radiation doses.
- Effects usually observed in thick (> 5 cm) crystals.
- A material is usually called radiation hard if no measurable effects occur at a dose of 10,000 Gray. Examples of radiation hard materials are CdWO_4 and GSO.

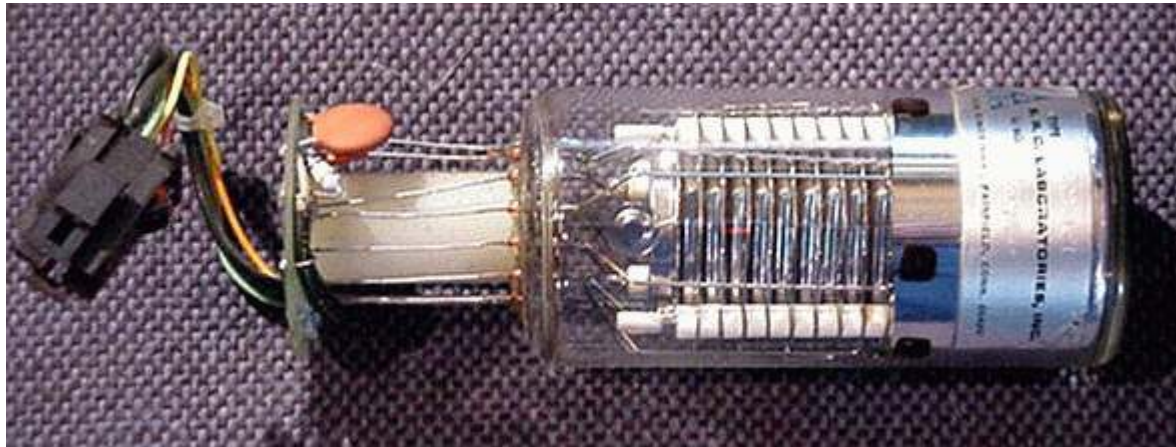
Detecting Scintillator Output:- PhotoCathode & Photomultiplier Tubes

- Radiation interaction in scintillator produces light (may be in visible range)
- Quantification of output requires light amplification and detection device(s)
- This is accomplished with the:
 - Photocathode
 - Photomultiplier tube
- Both components are
 - placed together as one unit
 - optically coupled to the scintillator

Cutaway diagram of solid-fluorescent scintillation detector

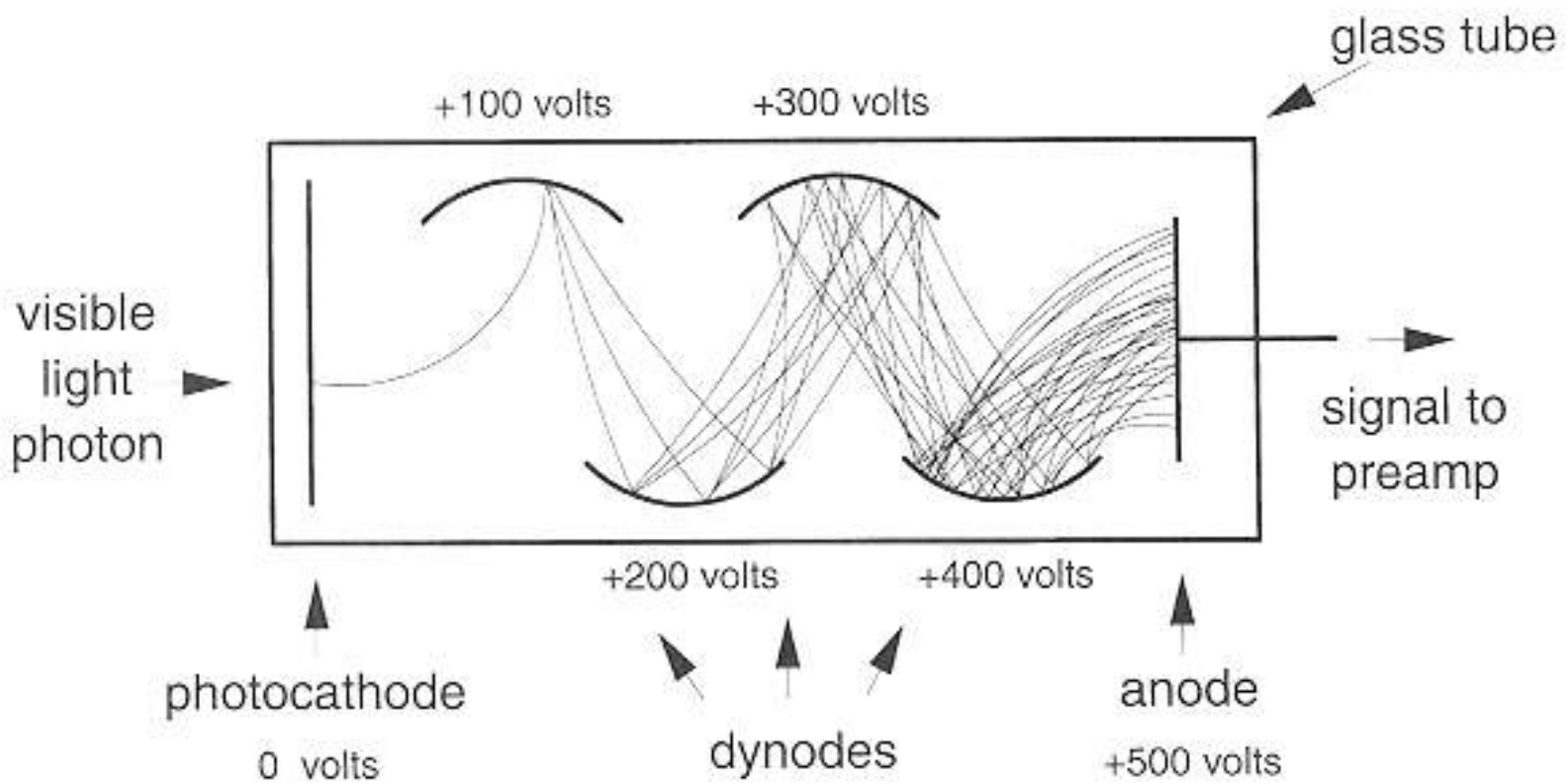


Photomultiplier



Photomultiplier tubes

- PMTs perform two functions:
 - Conversion of ultraviolet and visible light photons into an electrical signal
 - Signal amplification, on the order of millions to billions
- Consists of an evacuated glass tube containing a photocathode, typically 10 to 12 electrodes called dynodes, and an anode



Dynodes

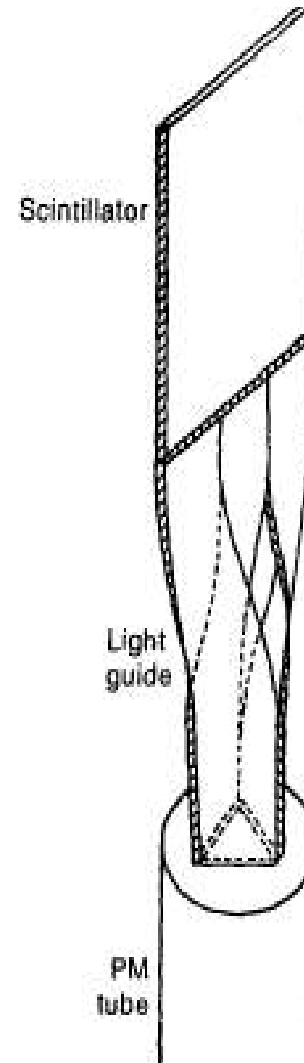
- Electrons emitted by the photocathode are attracted to the first dynode and are accelerated to kinetic energies equal to the potential difference between the photocathode and the first dynode
- When these electrons strike the first dynode, about 5 electrons are ejected from the dynode for each electron hitting it
- These electrons are attracted to the second dynode, and so on, finally reaching the anode

PMT amplification

- Total amplification of the PMT is the product of the individual amplifications at each dynode
- If a PMT has ten dynodes and the amplification at each stage is 5, the total amplification will be approximately 10,000,000
- Amplification can be adjusted by changing the voltage applied to the PMT

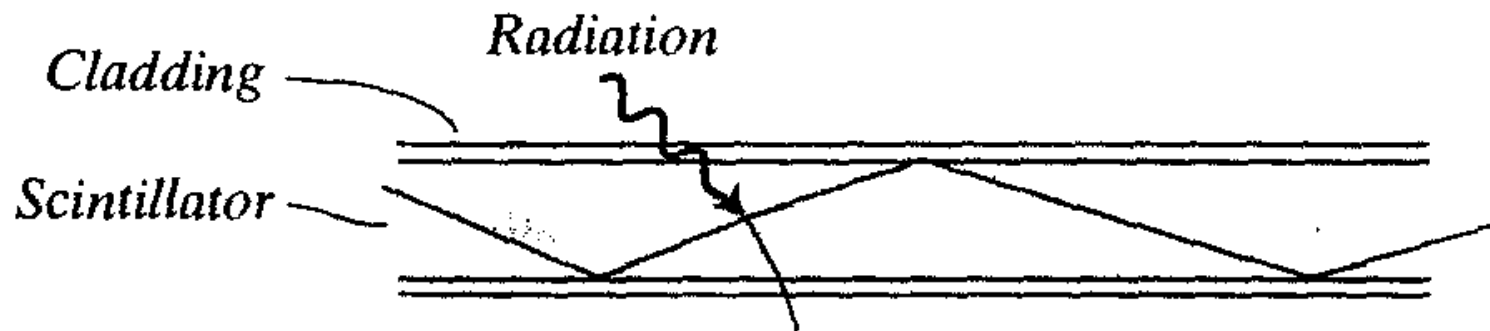
Light Collection and Scintillator Mounting

- Light Pipes



Fiber Scintillators

- Some scintillation materials can be fabricated as small diameter fibers in which a fraction of the scintillation light is conducted over substantial distance by the total internal reflection



Position-Sensing Photomultiplier Tubes

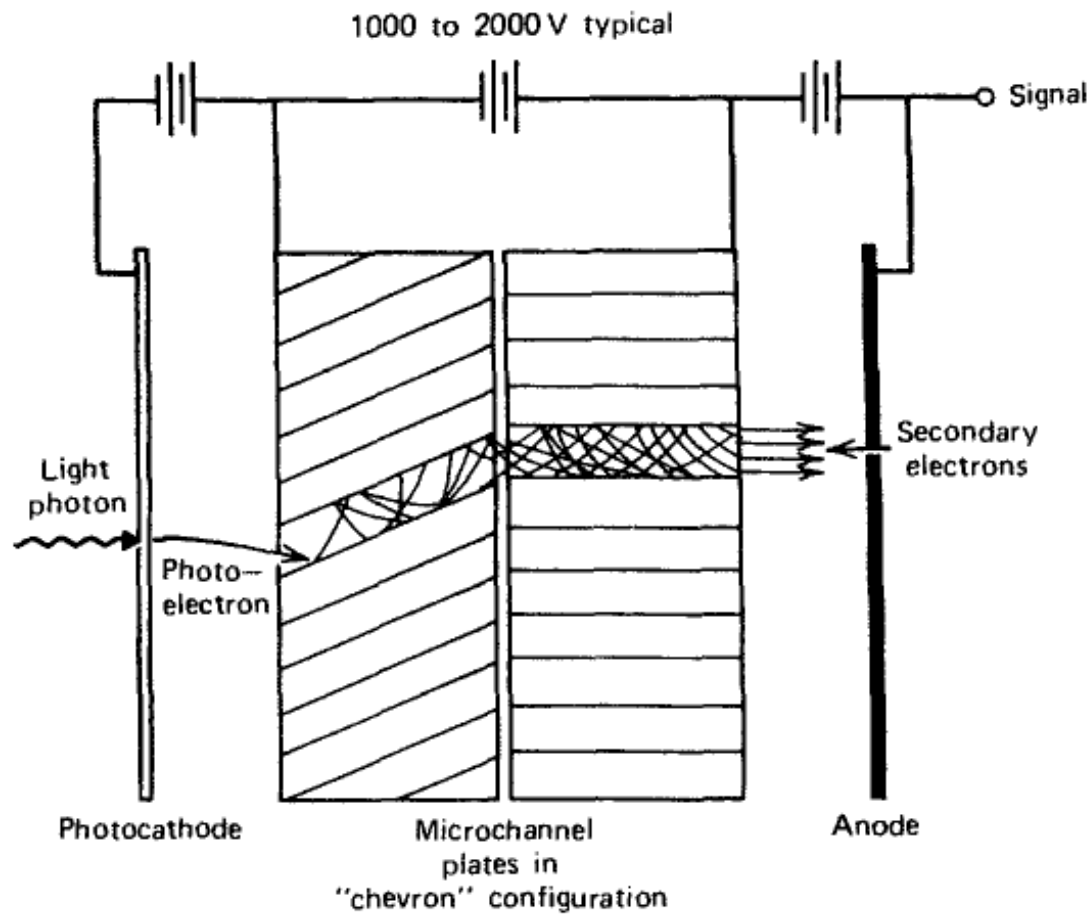


R8900-200-M16MOD-UBA

- Low noise
(1 p.e. level detectable)
- Position sensitive PMT
- Large effective surface
> 80 % physical area
- Compact
26 x 26 x 27 mm³
- Operate at low voltage
~ 900 V, gain ~ 2×10^6

- Ultra bi-alkali photo-cathode **Q.E. > 40 %**

Multichannel Plates



Field Applications for Liquid and Solid Scintillation Counters

- Solid Scintillators
 - in-situ measurement of low to high energy gammas
 - laboratory systems
 - spectroscopy
 - SCA or MCA mode
- Liquid Scintillators
 - wipe tests
 - contaminants in solids (concrete)
 - contaminants in aqueous/organic liquids

43-93 Alpha/Beta Scintillator

- The Model 43-93 is a 100 cm² dual phosphor alpha/beta scintillator that is designed to be used for simultaneously counting alpha and beta contamination



44-2 Gamma Scintillator

- The Model 44-2 is a 1" X 1" NaI(Tl) Gamma Scintillator that can be used with several different instruments including survey meters, scalars, ratemeters, and alarm ratemeters

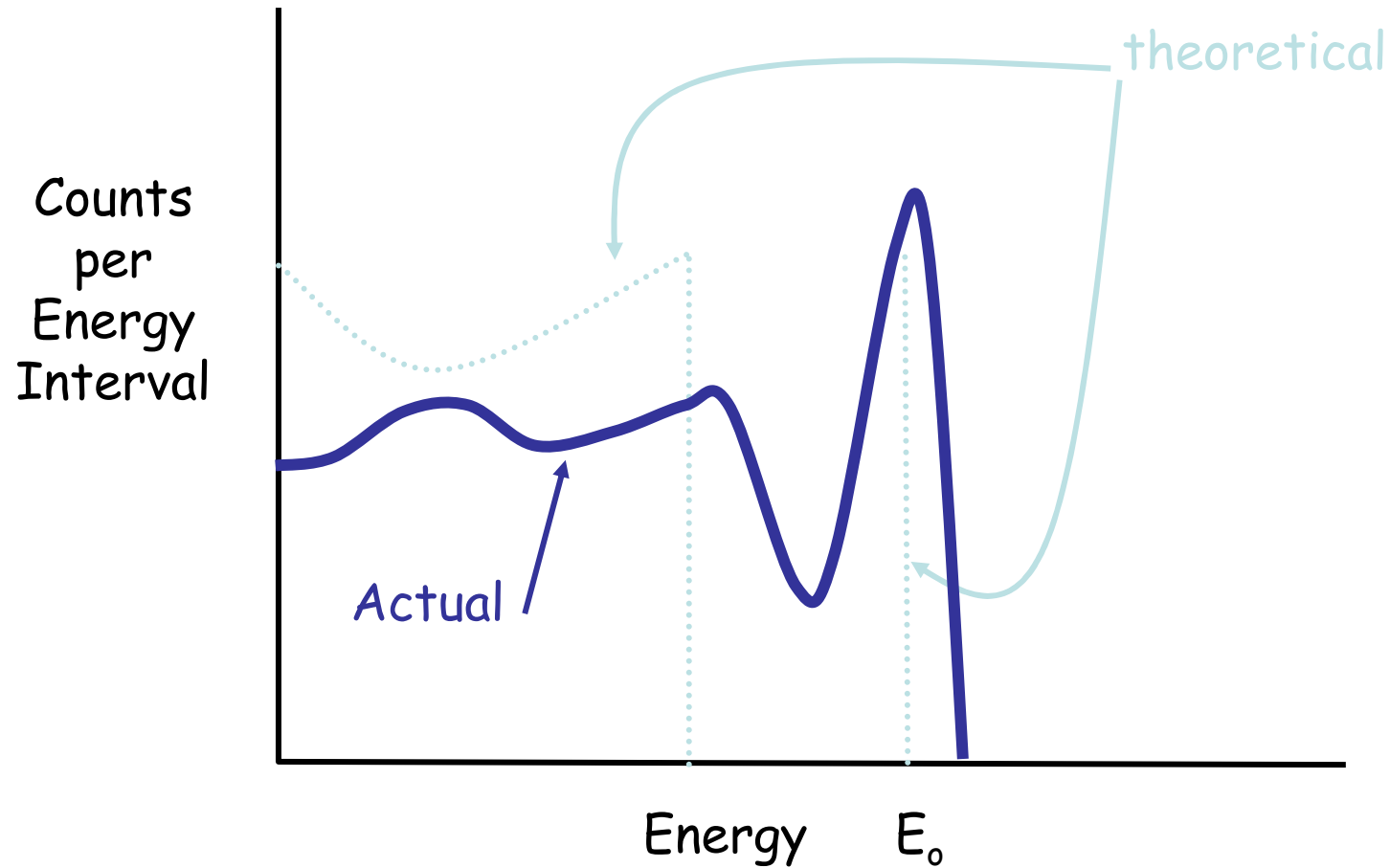


Semiconductor Detectors

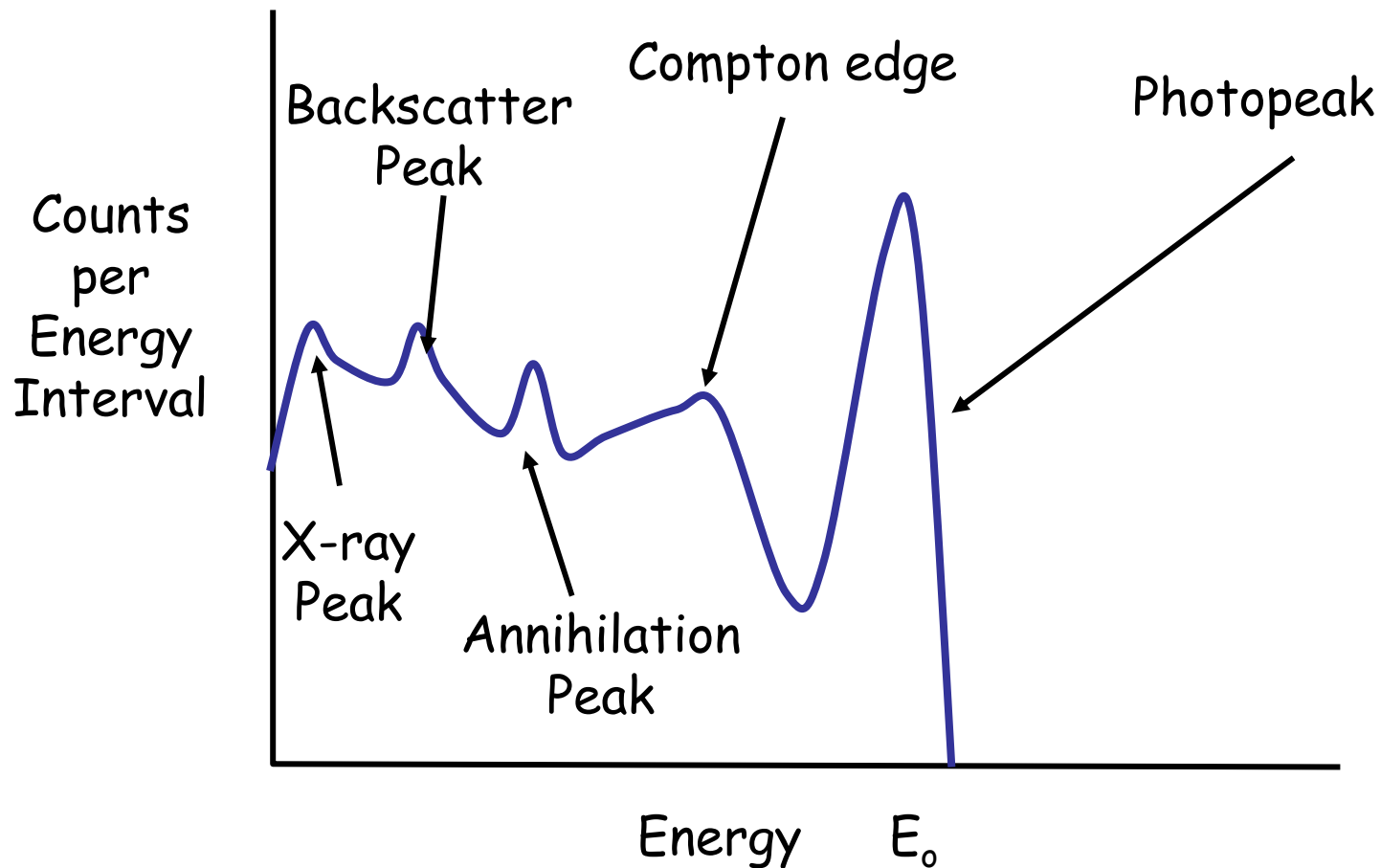
Semiconductor Detectors

- For the measurements of high energy electrons or gamma rays, solid detectors can be kept much smaller than the equivalent gas-filled detectors (solid densities 1000 times greater than for a gas).
- Scintillators have a poor energy resolution; the chain of events that must take place in converting the incident radiation energy to light and then to electrical signal involves many inefficient steps.

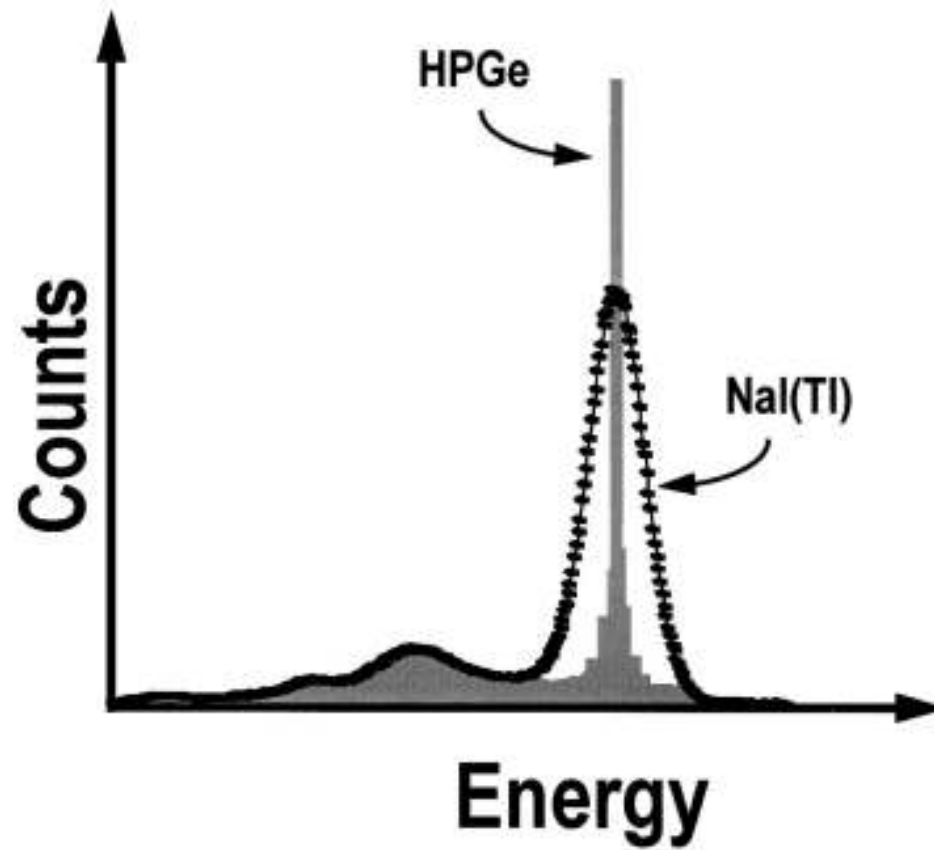
Idealized Gamma-Ray Spectrum in NaI



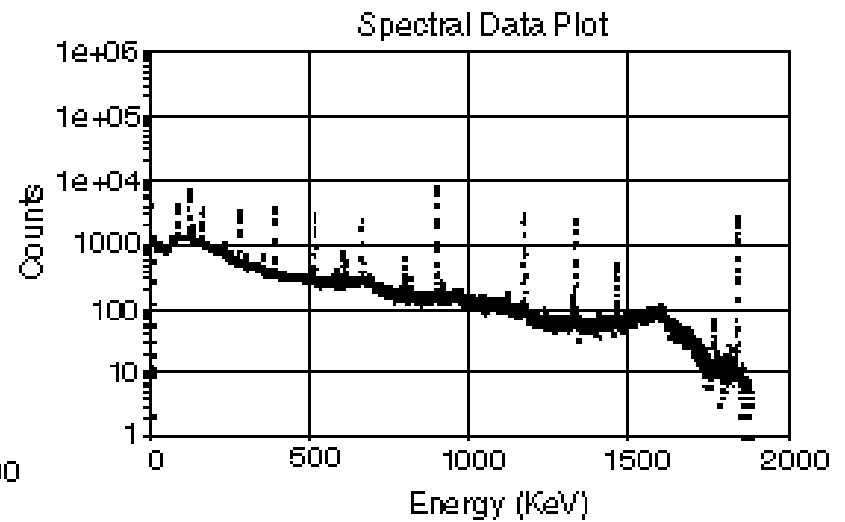
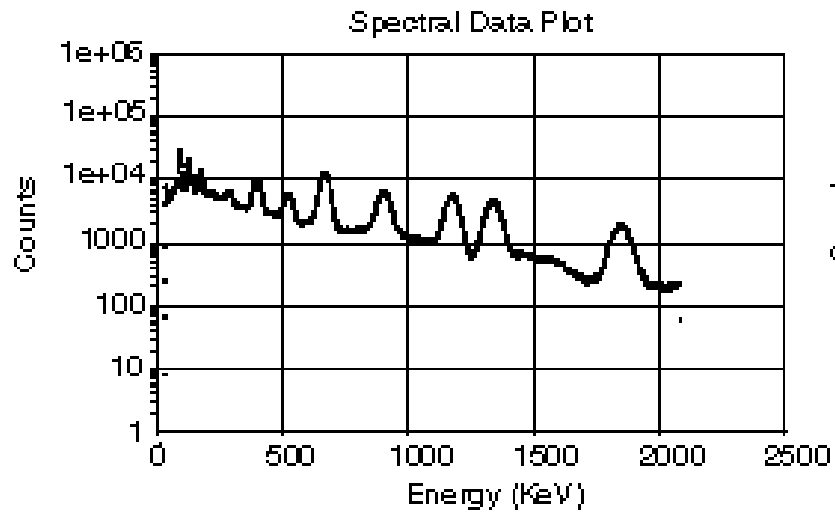
Components of Spectrum Semiconductor detector



NaI(Tl) vs. HPGe



NaI(Tl) vs. HPGE

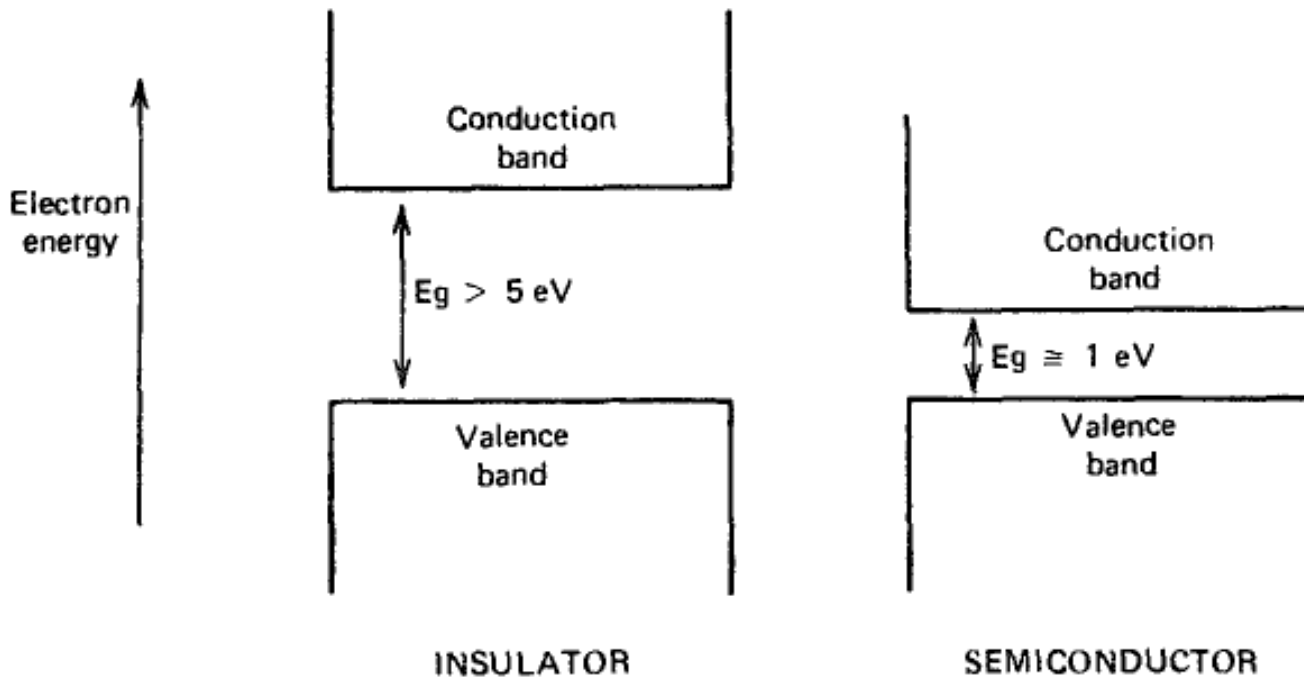


Semiconductor Detectors

- Solids have
 - lattice structure (molecular level)
 - quantized energy levels
 - valence bands
 - conduction bands
- Semiconductors have lattice structure
 - similar to inorganic scintillators
 - composed of Group IVB elements
 - ability to easily share electrons with adjoining atoms

Semiconductor Detectors

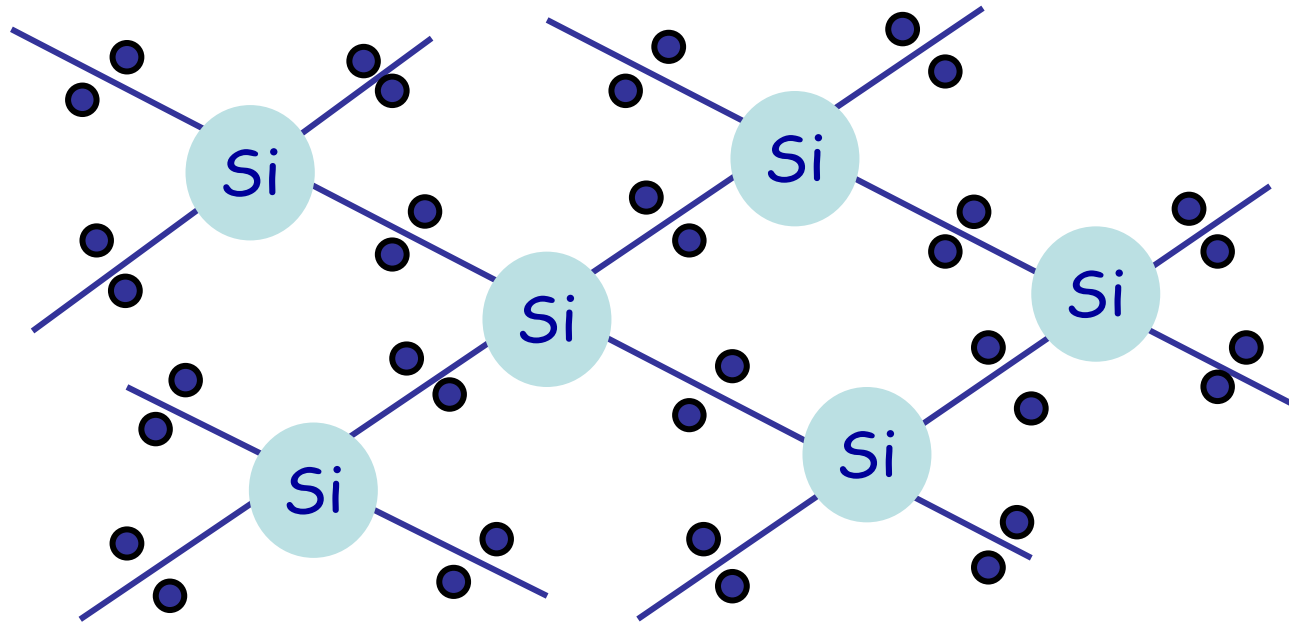
Band Structure



Basic Nature of Semiconductors

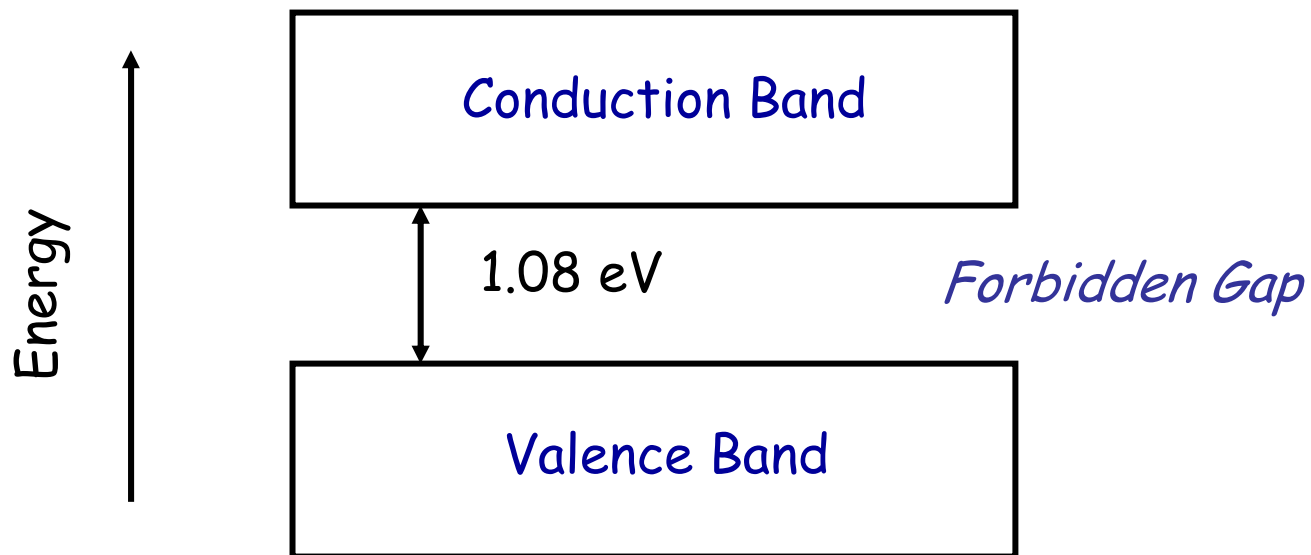
Si

- Schematic view of lattice of Group IVB element Si
- Dots represent electron pair bonds between the Si atoms



Basic Nature, Si, cont'd

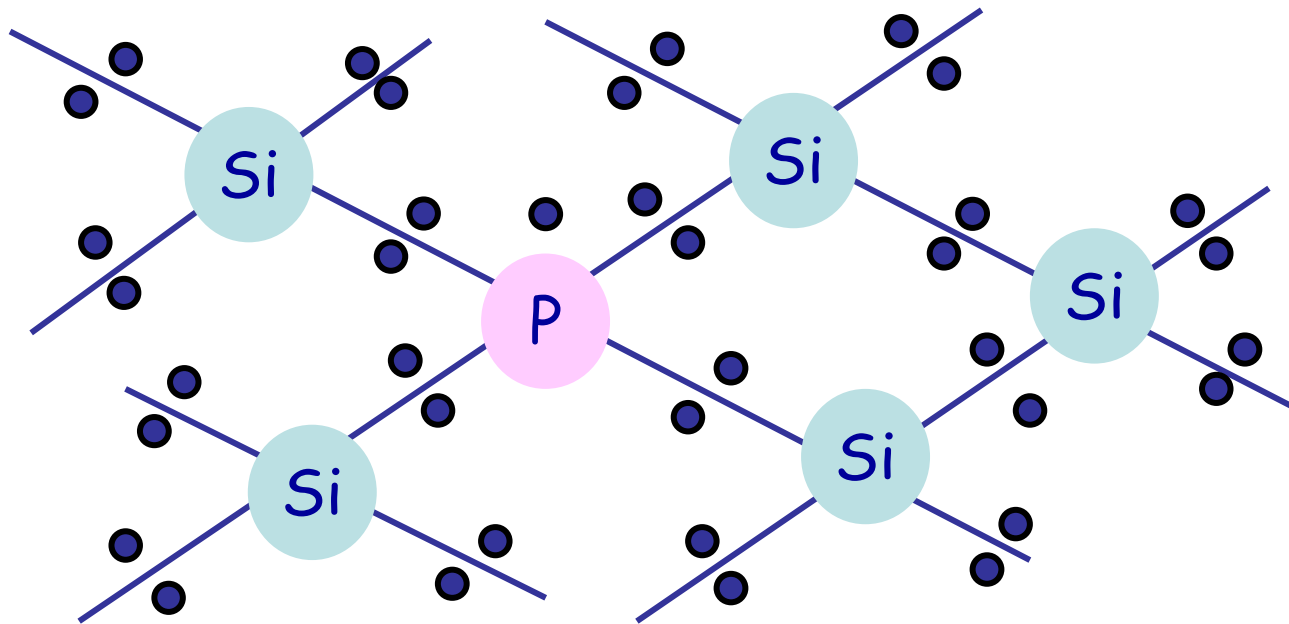
- Schematic diagram of energy levels of crystalline Si.



- Pure Si is a poor conductor of electricity

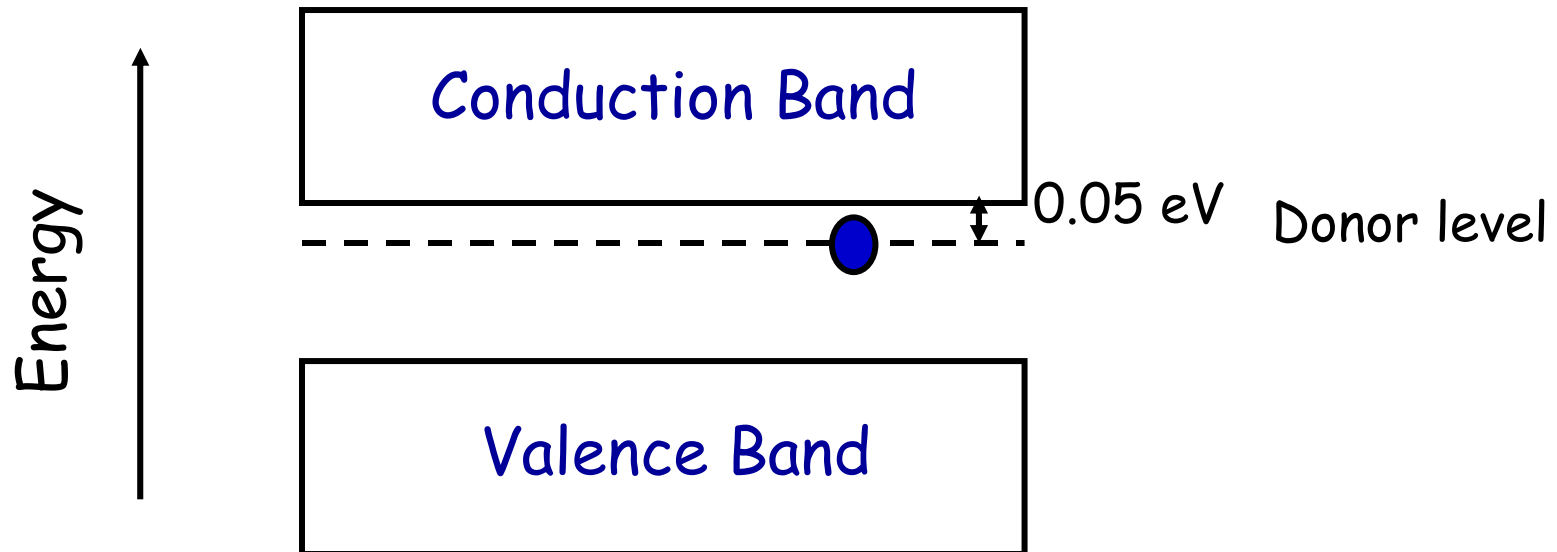
Basic Nature, Si, cont'd

- Schematic view of lattice of Group IV element Si, doped with P (Group VB) as an impurity – note extra electron



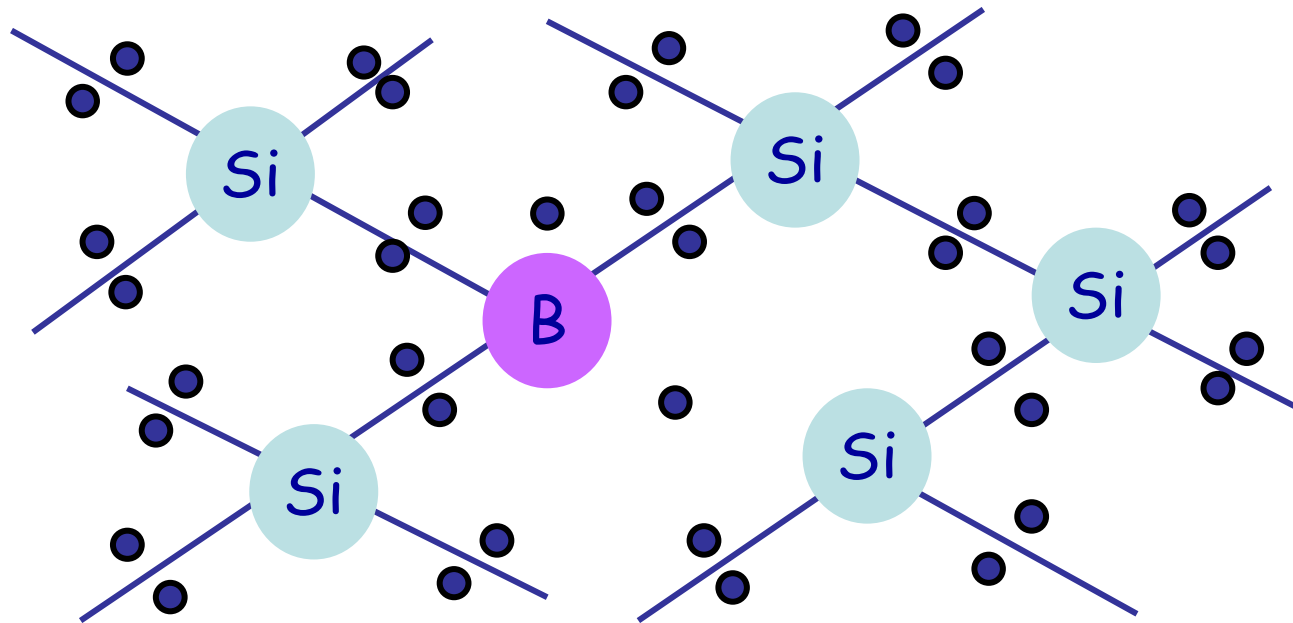
Basic Nature, Si, cont'd

- Schematic diagram of disturbed energy levels of crystalline Si.
- Si with Group V impurities like P is said to be an *n-type silicon* because of the negative charge carriers (the electrons)



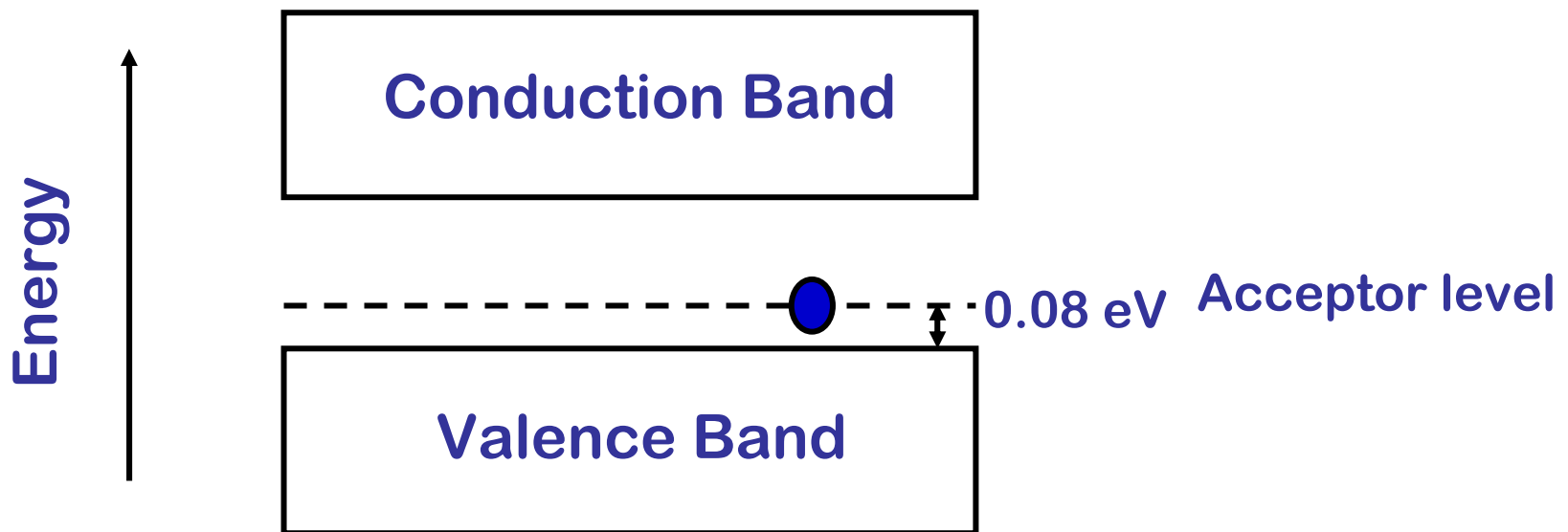
Basic Nature, Si, cont'd

- Schematic view of lattice of Group IV element Si, doped with B (Group IIIB) as an impurity – *note hole in electron orbital*



Basic Nature, Si, cont'd

- Schematic diagram of disturbed energy levels of crystalline Si with B impurity.



- Si with Group III impurities is said to be a p-type silicon because of the positive charge carriers (the holes)

Operating Principles of Semiconductor Diode detectors

- Si Semiconductor Diode is a layer of p-type Si in contact with n-type Si.
- What happens when this junction is created?
 - Electrons from n-type migrate across junction to fill holes in p-type
 - Creates an area around the p-n junction with no excess of holes or electrons
 - Called a “depletion region”
- Apply (+) voltage to n-type and (-) to p-type:
 - Depletion region made thicker
 - Called a “reverse bias”

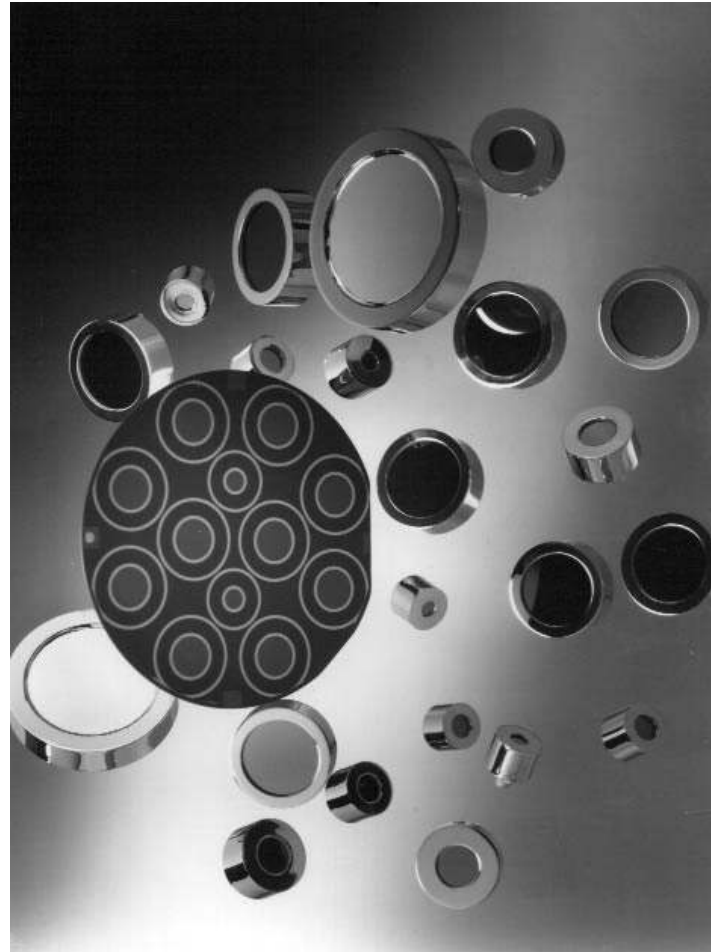
Diode Detector specifications

- Depletion region acts as sensitive volume of the detector
- Passage of ionizing radiation through the region
 - Creates holes in valence band
 - Electrons in conduction band
 - Electrons migrate to positive charge on n side
 - Holes migrate to negative voltage on p side
 - Creates electrical output
- Requires about 3.6 eV to create an electron hole pair in Si

Diode Detector Specifications

- Reverse bias n-p junction is good detector
- Depletion region
 - Has high resistivity
 - Can be varied by changing bias voltage
 - Electrical charges produced can be quickly collected
 - Number of charged pairs collected is proportional to energy deposited in detector
 - Junction can be used as a spectrometer

Semiconductor Detectors for Alpha Spectroscopy



Germanium Gamma-Ray Detectors

- The simple junction and surface barrier detectors are not so suitable for more penetrating radiation than alpha particles. The major limitation is the maximum depletion depth or active volume; maximum depletion is about 2 mm in normal purity semiconductors.

Germanium Gamma-Ray Detectors

- Germanium detectors produced by lithium drifting process, Ge(Li), have a thickness up to 2 cm. After the growth of the germanium crystal, interstitial lithium donors atoms are added in order to compensate the residual acceptor impurities.
- High Purity Germanium detectors with a impurity concentration of 10^{10} atoms/cm³ have a depletion depth of several cm.

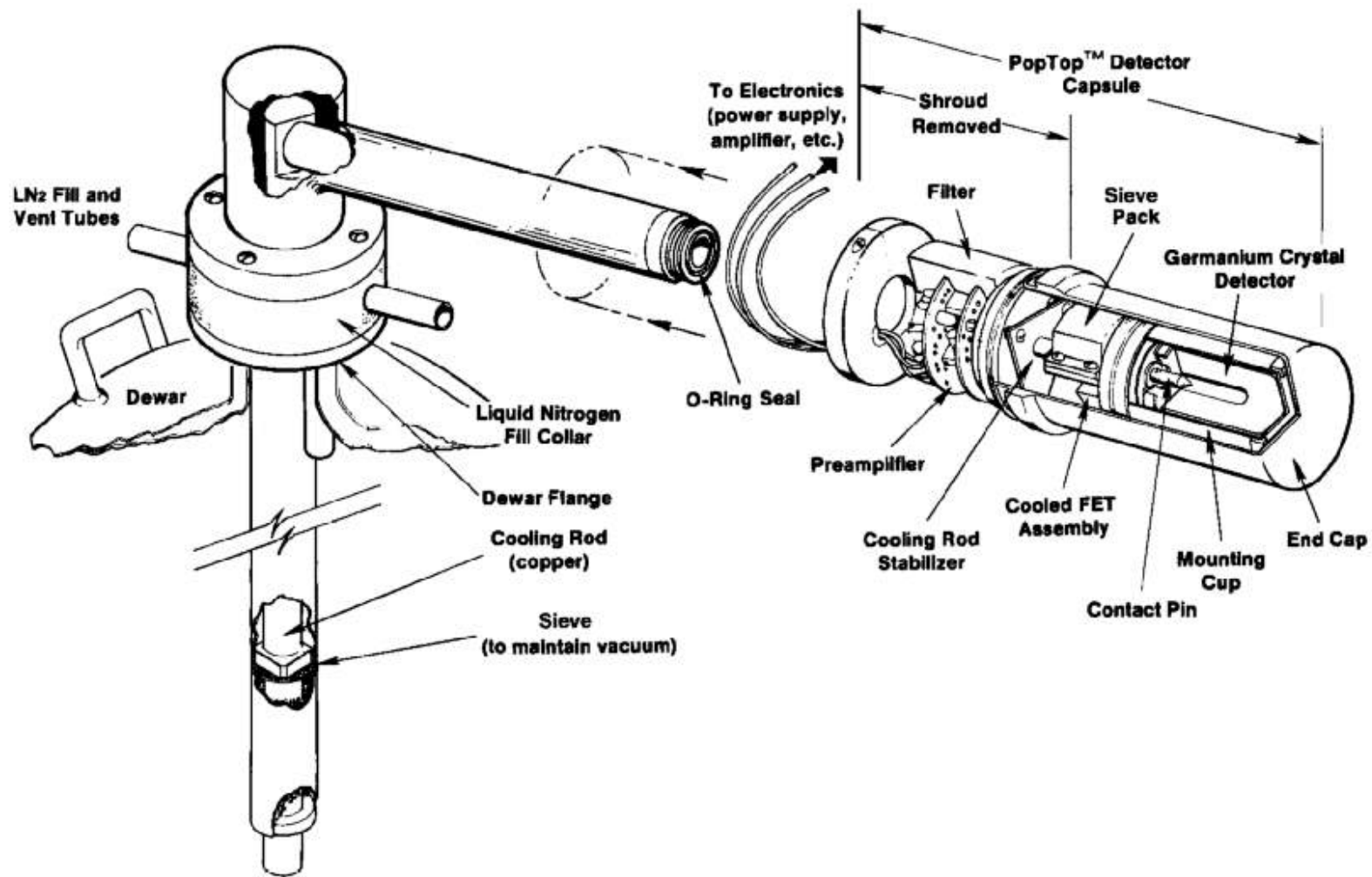
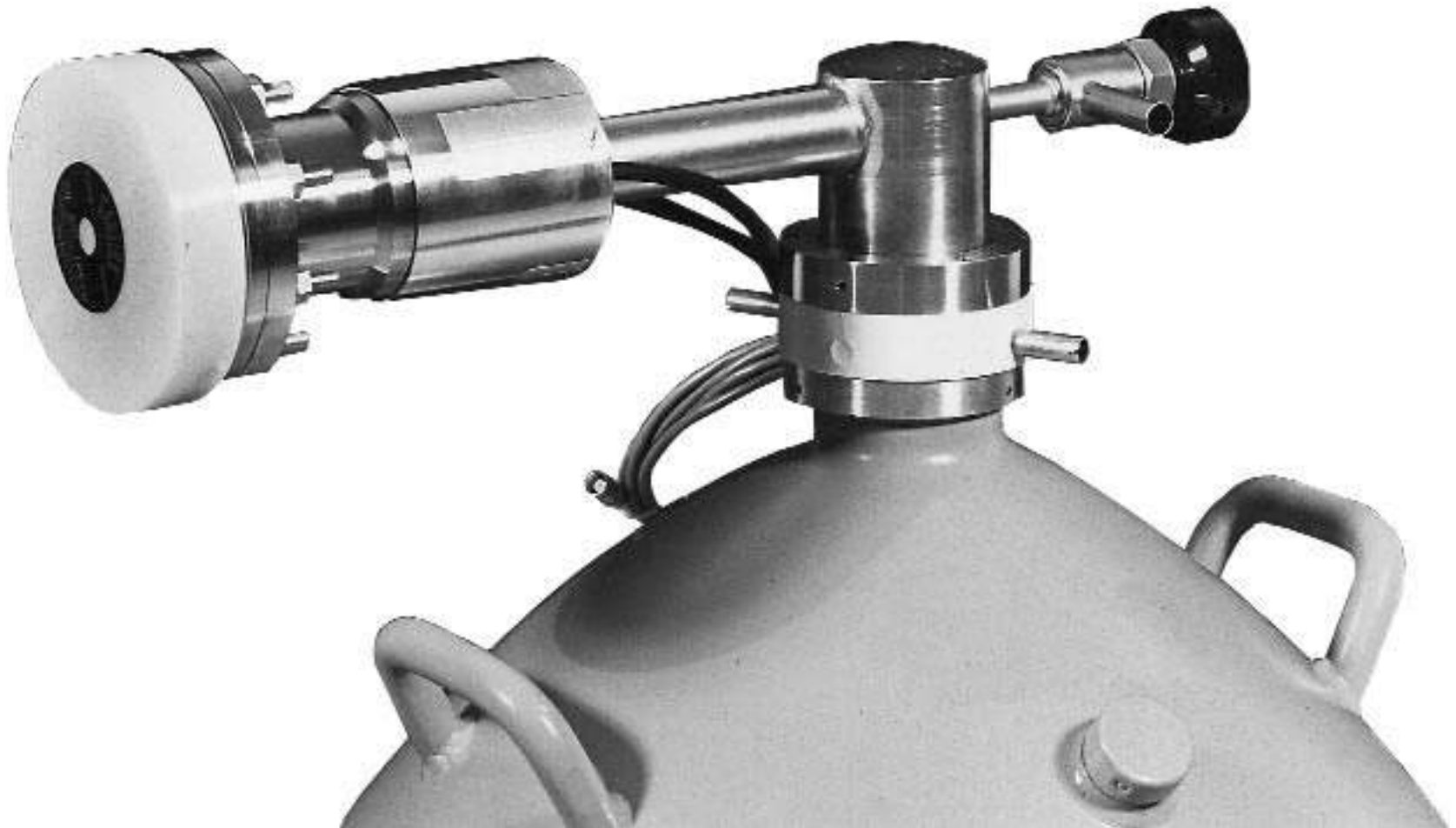
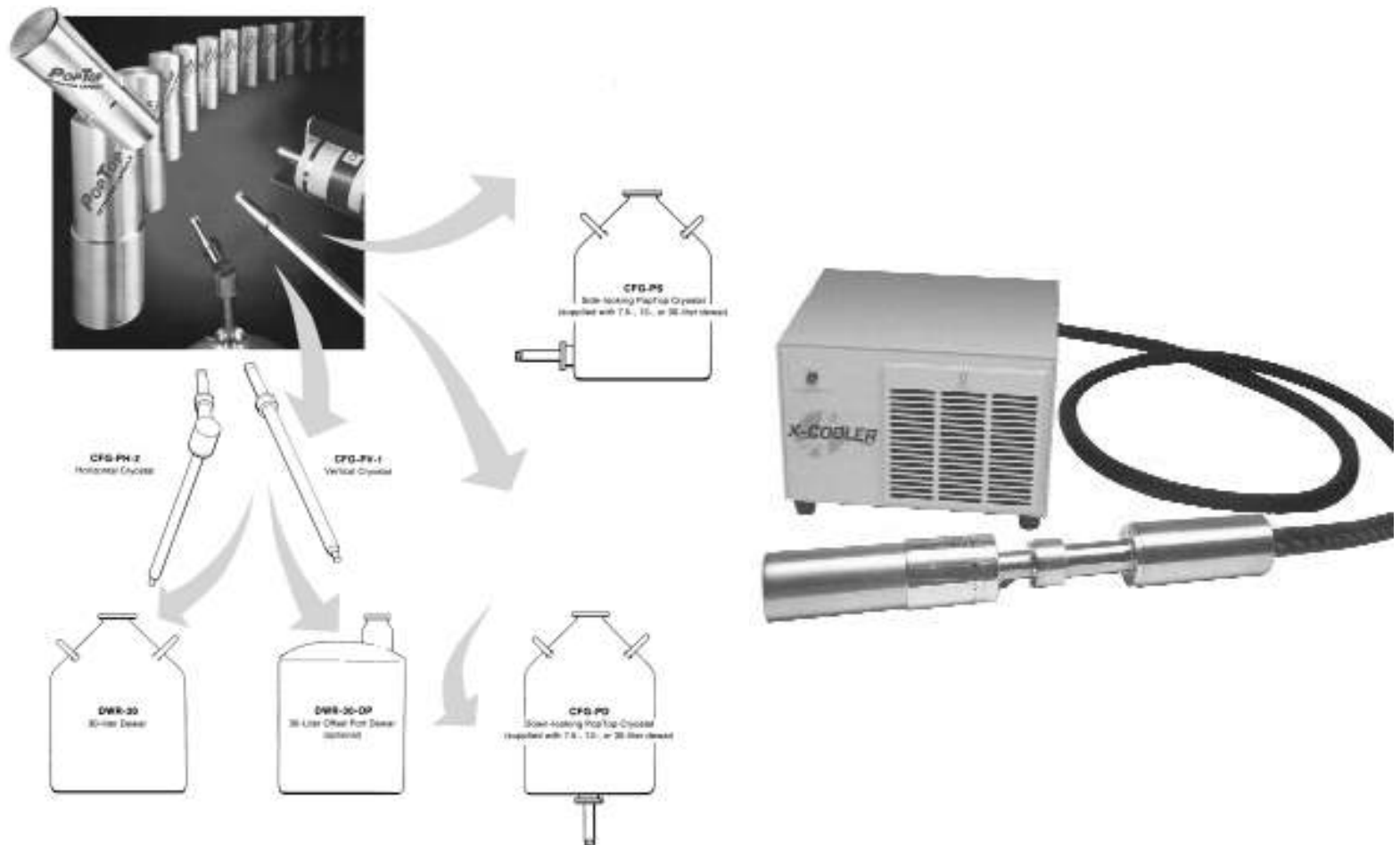


Fig. 9. A Typical Cryostat System.

Cooled Semiconductor Detector



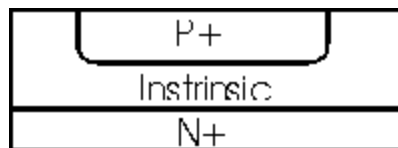
Cooled Semiconductor Detector



Positive Intrinsic Negative Diodes

Energy compensated PIN diodes and special photodiodes are used as pocket electronic (active) dosimeters.

- PIN diode: Acronym for positive-intrinsic-negative diode.
- A photodiode with a large, neutrally doped intrinsic region sandwiched between p-doped and n-doped semiconducting regions.
- A PIN diode exhibits an increase in its electrical conductivity as a function of the intensity, wavelength, and modulation rate of the incident radiation.
Synonym PIN photodiode.



PIN Diodes

- Ordinary Silicon PIN photodiodes can serve as detectors for X-ray and gamma ray photons. The detection efficiency is a function of the thickness of the silicon wafer. For a wafer thickness of 300 microns (ignoring attenuation in the diode window and/or package) the detection efficiency is close to 100% at 10 KeV, falling to approximately 1% at 150 KeV(3).
- For energies above approximately 60 KeV, photons interact almost entirely through Compton scattering. Moreover, the active region of the diode is in electronic equilibrium with the surrounding medium--the diode package, substrate, window and outer coating, etc., so that Compton recoil electrons which are produced near--and close enough to penetrate--the active volume of the diode, are also detected.
- For this reason the overall detection efficiency at 150 KeV and above is maintained fairly constant (approximately 1%) over a wide range of photon energies.
- Thus, a silicon PIN diode can be thought of as a solid-state equivalent to an ionization-chamber radiation detector.

Positrons emission tomography



SPIN 224



SPIN 224



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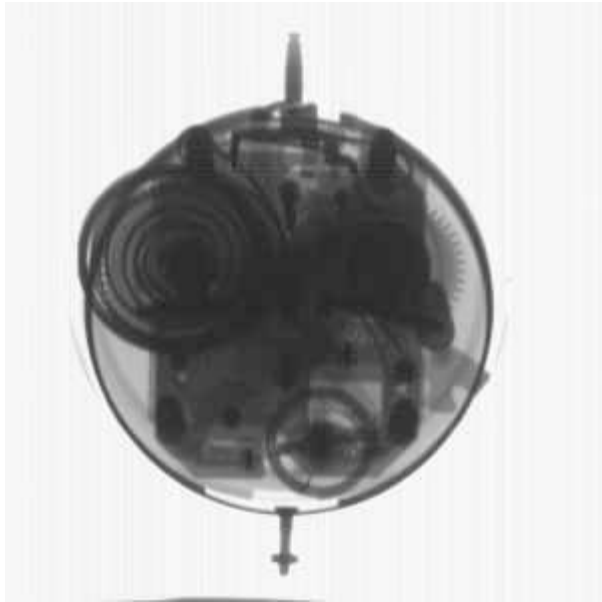
Digital Radiography



Digital Radiography

- Receptor Type Amorphous Silicon
- Conversion Screen DRZ Plus
- Pixel Area Total 29.3 x 40.6 cm (11.5 in. x 16.0 in)
- Active 29.1 x 40.5 cm (11.5 in. x 16.0 in)
- Pixel Matrix Total 2,304 (h) x 3,200 (v)
- Active 2,304 (h) x 3,200 (v)
- Pixel Pitch 127 μ m
- Limiting Resolution 3.94 lp/mm
- DQE (with DRZ Plus) > 30%
- MTF, X-Ray (with DRZ Plus) >45% (1 lp/mm)
- Energy Range 40 - 150 kVp
- Fill Factor 57%
- Contrast Ratio Large Area (12 cm): <2%
- Small Area (1 cm): <10%
- Scan Method Progressive
- A/D Conversion 14-bits
- Frame Rate 3 fps (1 x 1)
- 7 fps (2 x 2)
- Data Output Gigabit Ethernet

Digital Radiography



Another type of Solid State / Scintillation system

Thermoluminescent Dosimeters

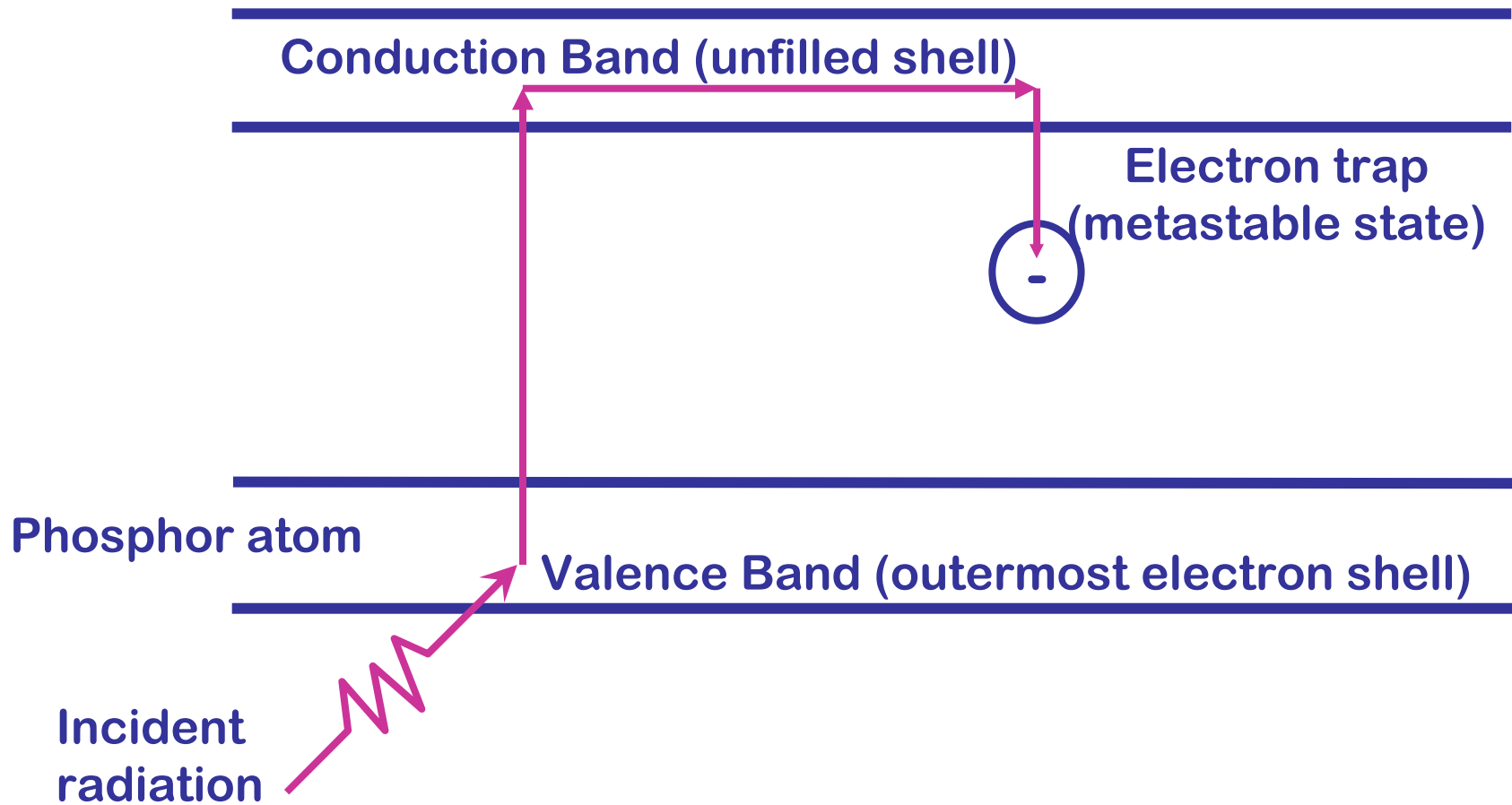
Thermoluminescence

- (TL) is the ability to convert energy from radiation to a radiation of a different wavelength, normally in the visible light range.
- Two categories
 - Fluorescence - emission of light during or immediately after irradiation
 - Not a particularly useful reaction for TLD use
 - Phosphorescence - emission of light after the irradiation period. Delay can be seconds to months.
- TLDs use phosphorescence to detect radiation.

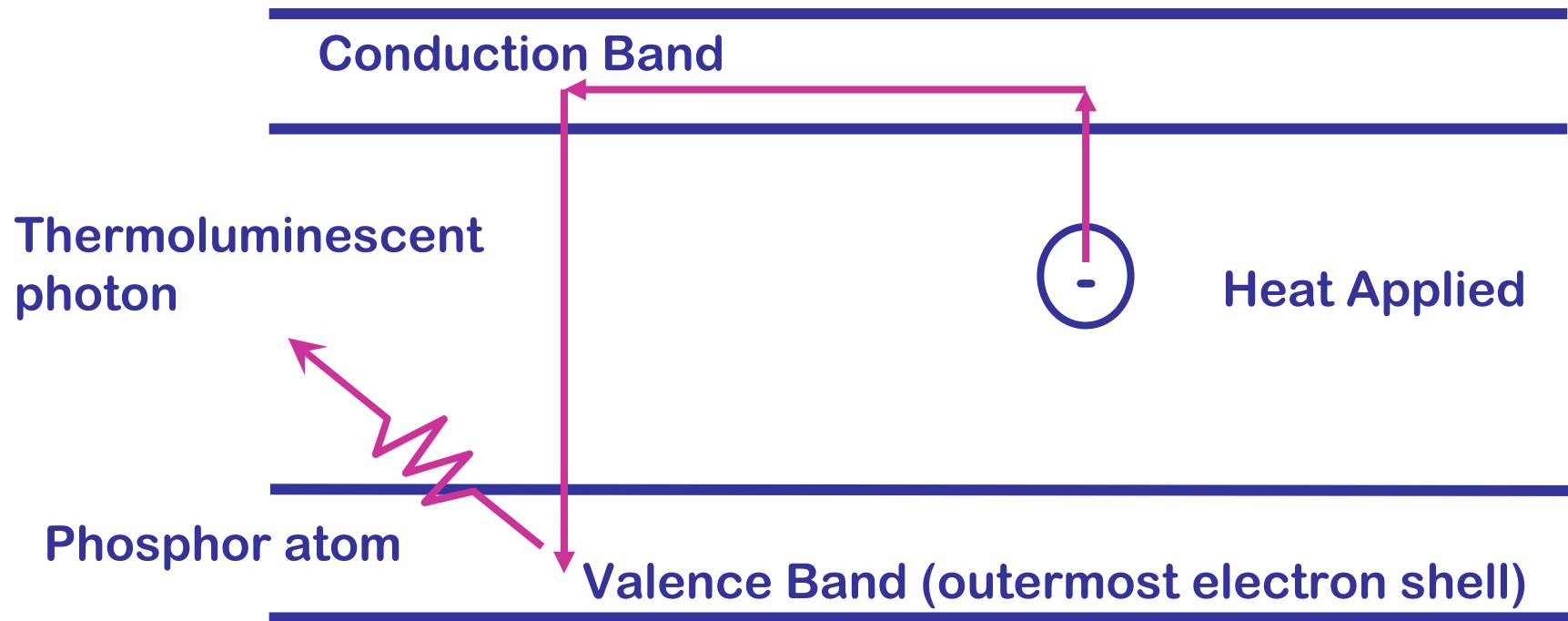
Thermoluminescence

- Radiation moves electrons into “traps”
- Heating moves them out
- Energy released is proportional to radiation
- Response is \sim linear
- High energy trap data is stored in TLD for a long time

TL Process



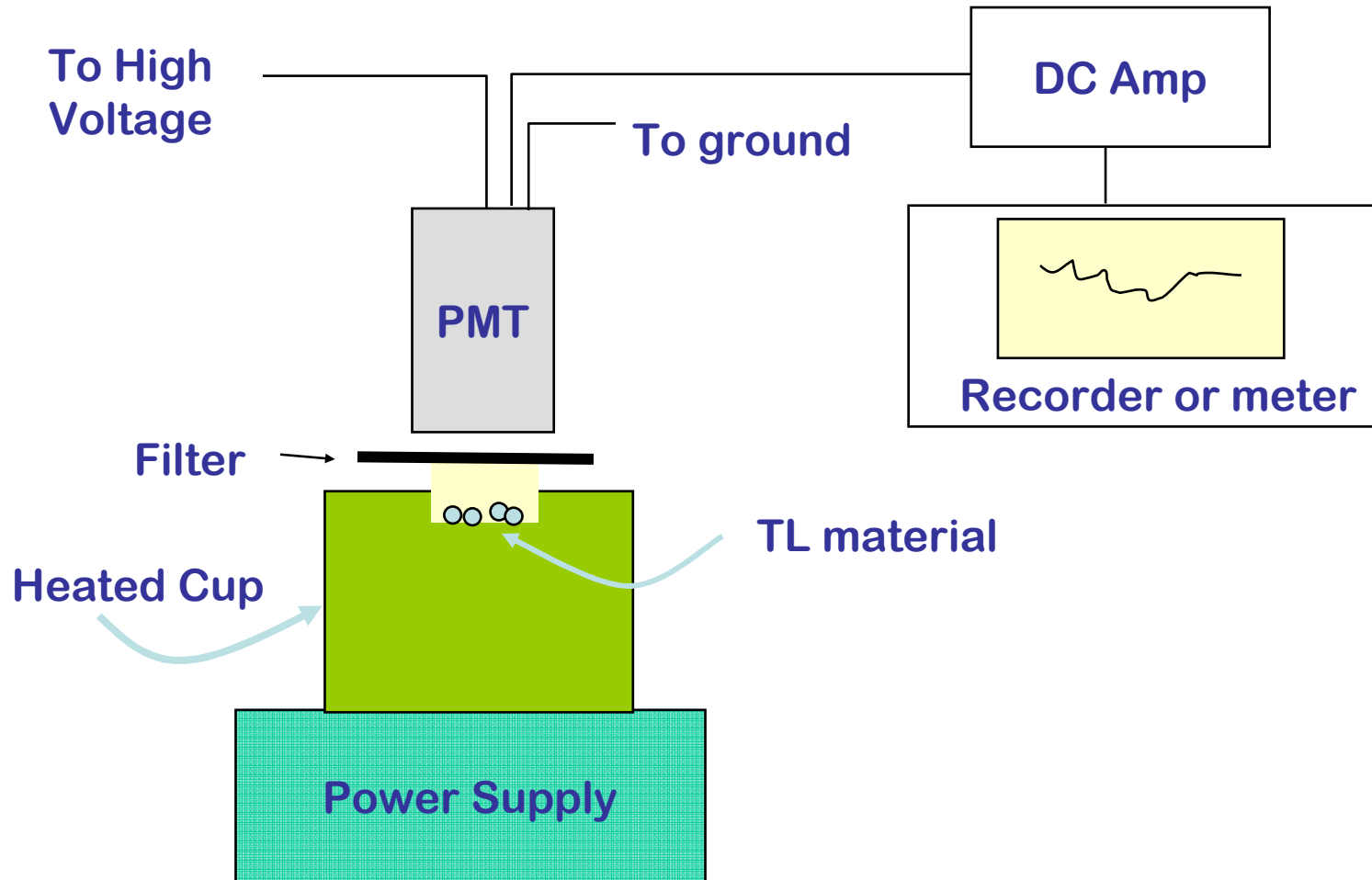
TL Process, continued



Output – Glow Curves

- A glow curve is obtained from heating
- Light output from TLs not easily interpreted
- Multiple peaks result from electrons in "shallow" traps
- Peak results as traps are emptied.
- Light output drops off as these traps are depleted.
- Heating continues
- Electrons in deeper traps are released.
- Highest peak is typically used to calculate dose
- Area under represents the radiation energy deposited in the TLD

TLD Reader Construction



Advantages

- Advantages (as compared to film dosimeter badges) includes:
 - Able to measure a greater range of doses
 - Doses may be easily obtained
 - They can be read on site instead of being sent away for developing
 - Quicker turnaround time for readout
 - Reusable
 - Small size
 - Low cost

TLD Disadvantages

- Lack of uniformity – batch calibration needed
- Storage instability
- Fading
- Light sensitivity
- Spurious TL (cracking, contamination)
- Reader instability
- No permanent record

Intrebari

- Numiti cele trei tipuri de detectoare clasice
- Enumerati domeniile de functionare ale detectoarelor cu gaz
- Care este diferenta principala intre scintilatorii organici si cei anorganici cristalini ?
- Care materiale se folosesc la fabricarea detectorilor cu semiconductori ?
- Care este diferenta principiala intre dispozitivele termoluminiscente si scintilatori.