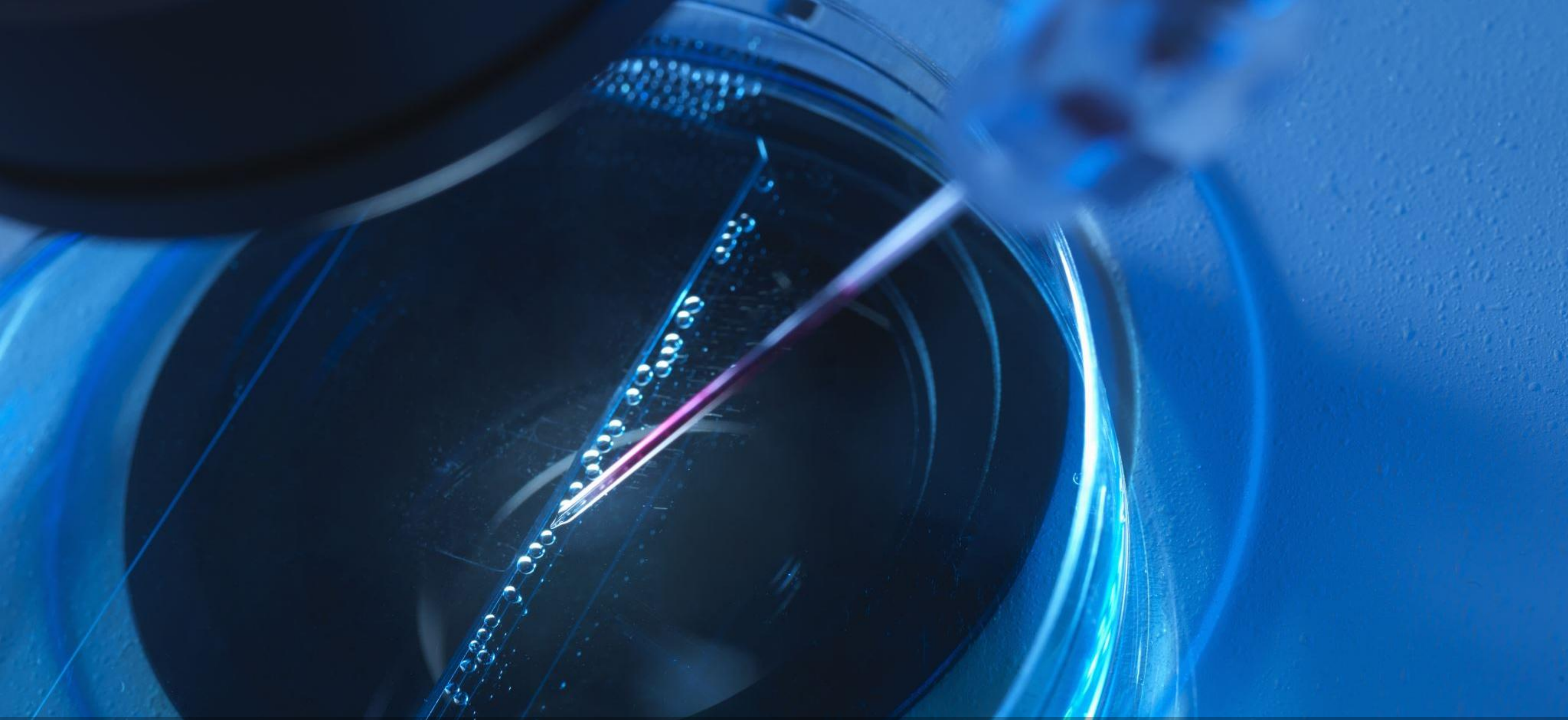


Detection of Radiation II

RT4220 – Lecture #11

Kedree Proffitt

WSU

10/23/2025

Semiconductors

Why would trucks need musical direction?

Bushberg Summary: Types of Detectors

Detection Method:

- Ionization of material between electrodes (**gaseous**)
- Production of light via UV excitation or visible light (**scintillators**)
- Film Exposure (**film**)
- Diode Activation (**semiconductor**)

Information Produced:

- **Counters**
  - GM
- **Spectrometers**
  - Scintillators
- **Dosimeters**
  - Ionization Chambers

Operating Modes

Pulse Mode:

- Each *event* is processed individually

Charge Mode:

- Individual interactions are averaged together to form a net signal

Semiconductor Detector Motivation

- Semiconductor detectors are a form of **solid-state** detector
- Analogous to **ionization chambers** or **proportional counters** in *purpose*
  - The size of the signal is proportional to energy deposited
- Commonly use **amorphous silicon**, sometimes germanium or CZT
- Ion production is MUCH more efficient in solid-state:
  - Air: 34 eV/i.p.
  - Si: 3.6 eV/i.p.
  - Ge: 2.8 eV/i.p.
- Because of the increased sensitivity and energy dependence → can **count individual events** and **differentiate energies**

How Semiconductors Work

Electrons exist in energy bands (valence, conduction)

In semiconductors, the forbidden zone between the bands is very small (1 ev or less)

Sources of energy (such as ionization, UV, or heat) can move electrons in valence band to conduction band

This creates current, if a voltage is applied

The current created is tiny, we use **doping** to turn the material into a **diode** so that we can see the tiny current

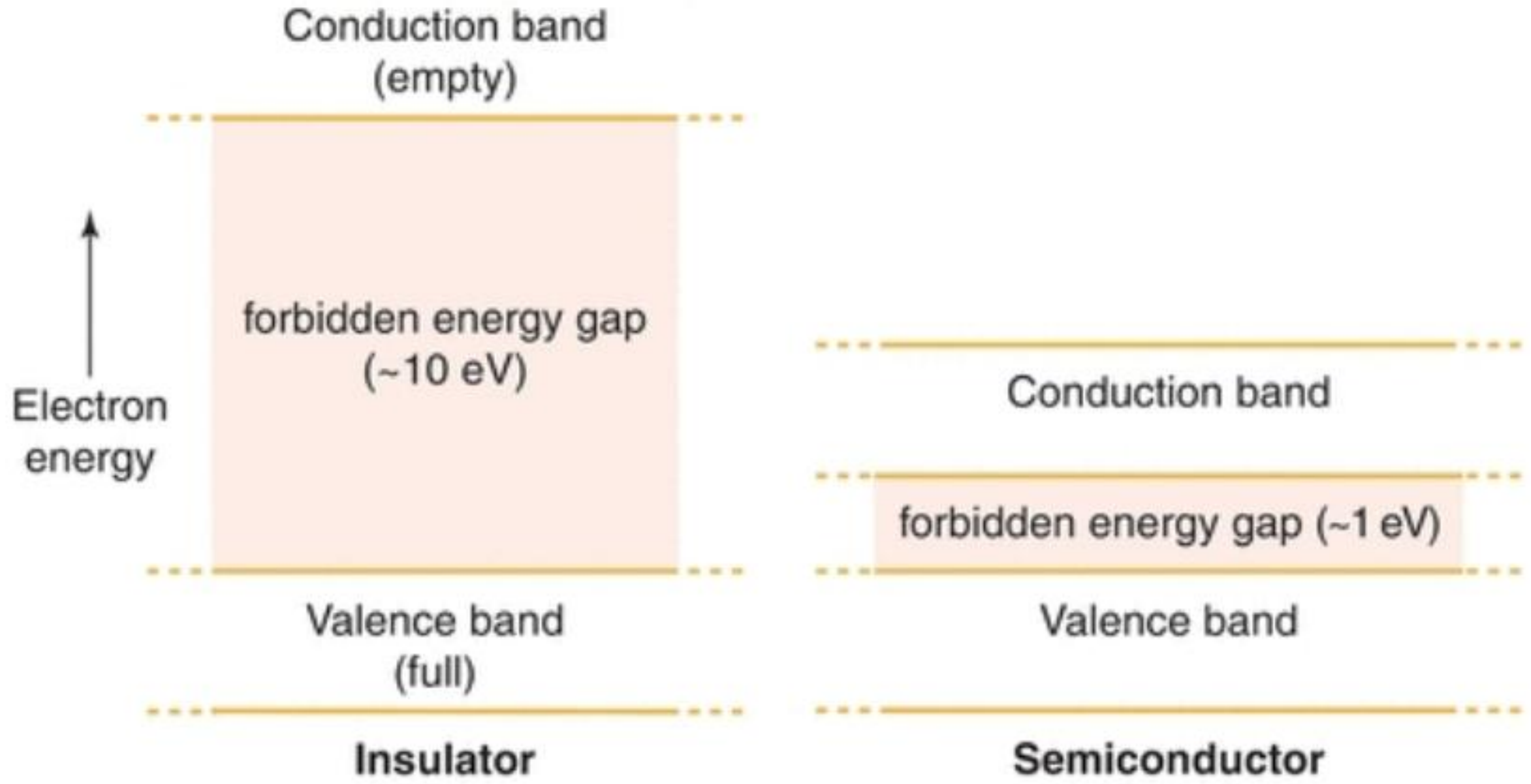
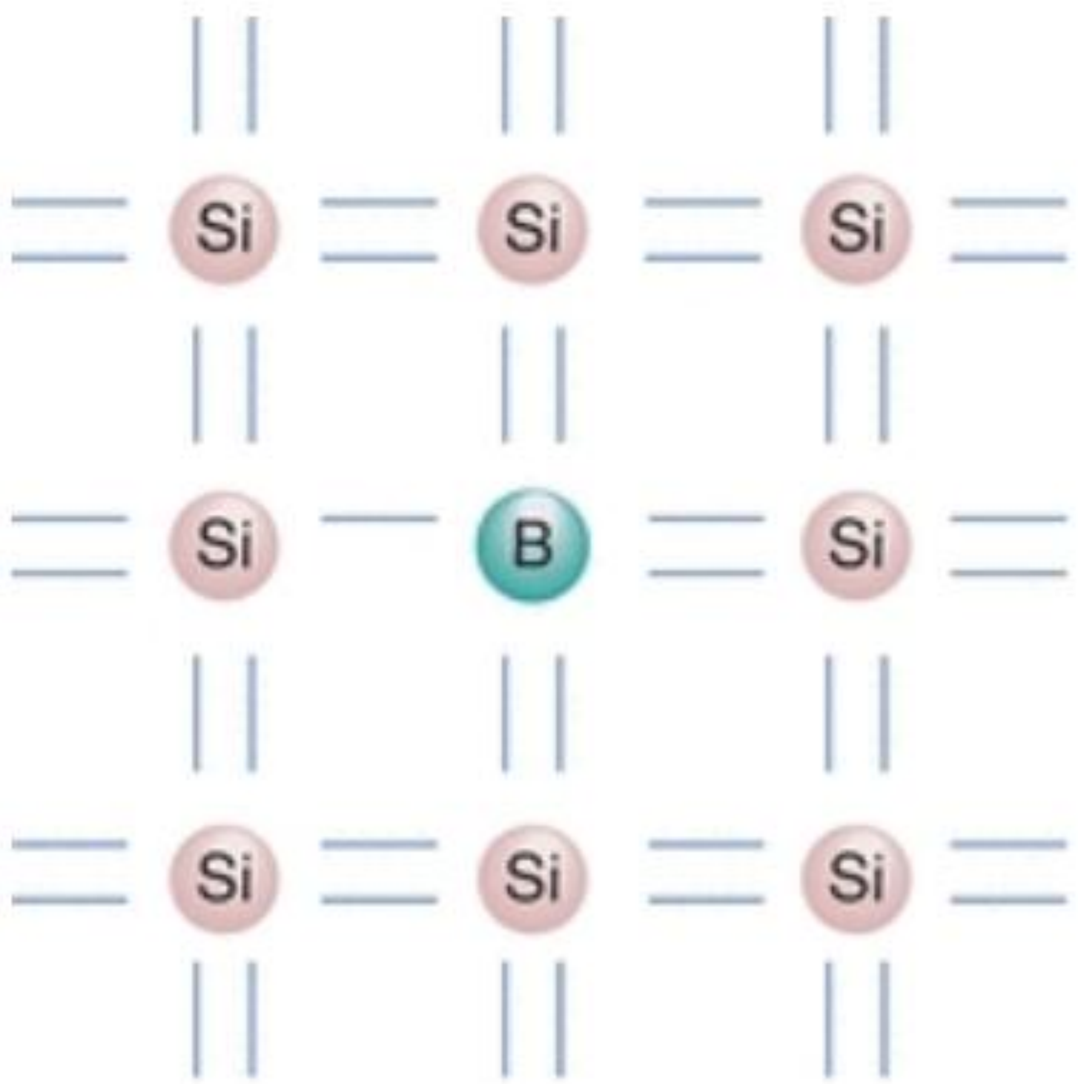


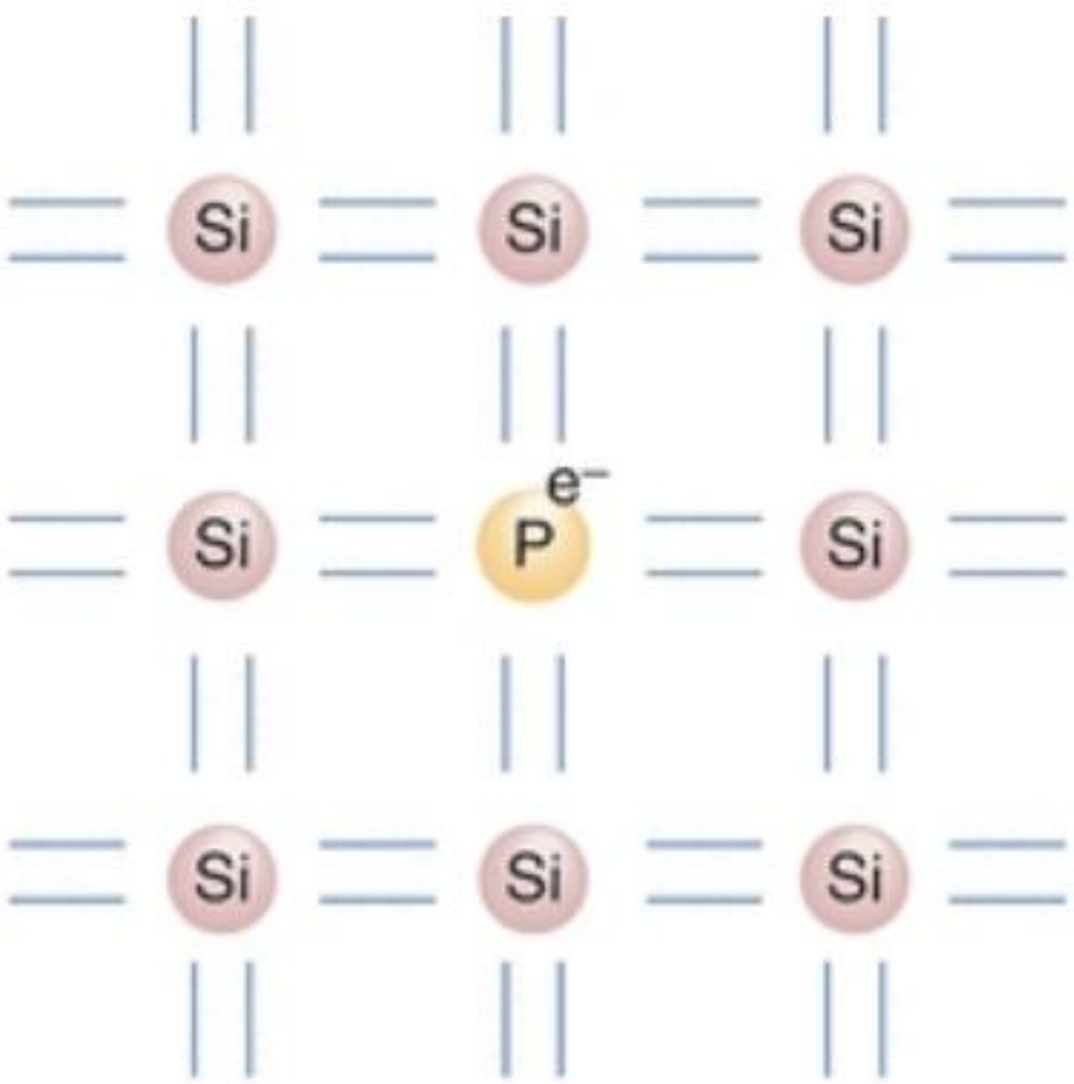
FIGURE 17-10 Energy band structure of a crystalline insulator and a semiconductor material.

How Diodes Work

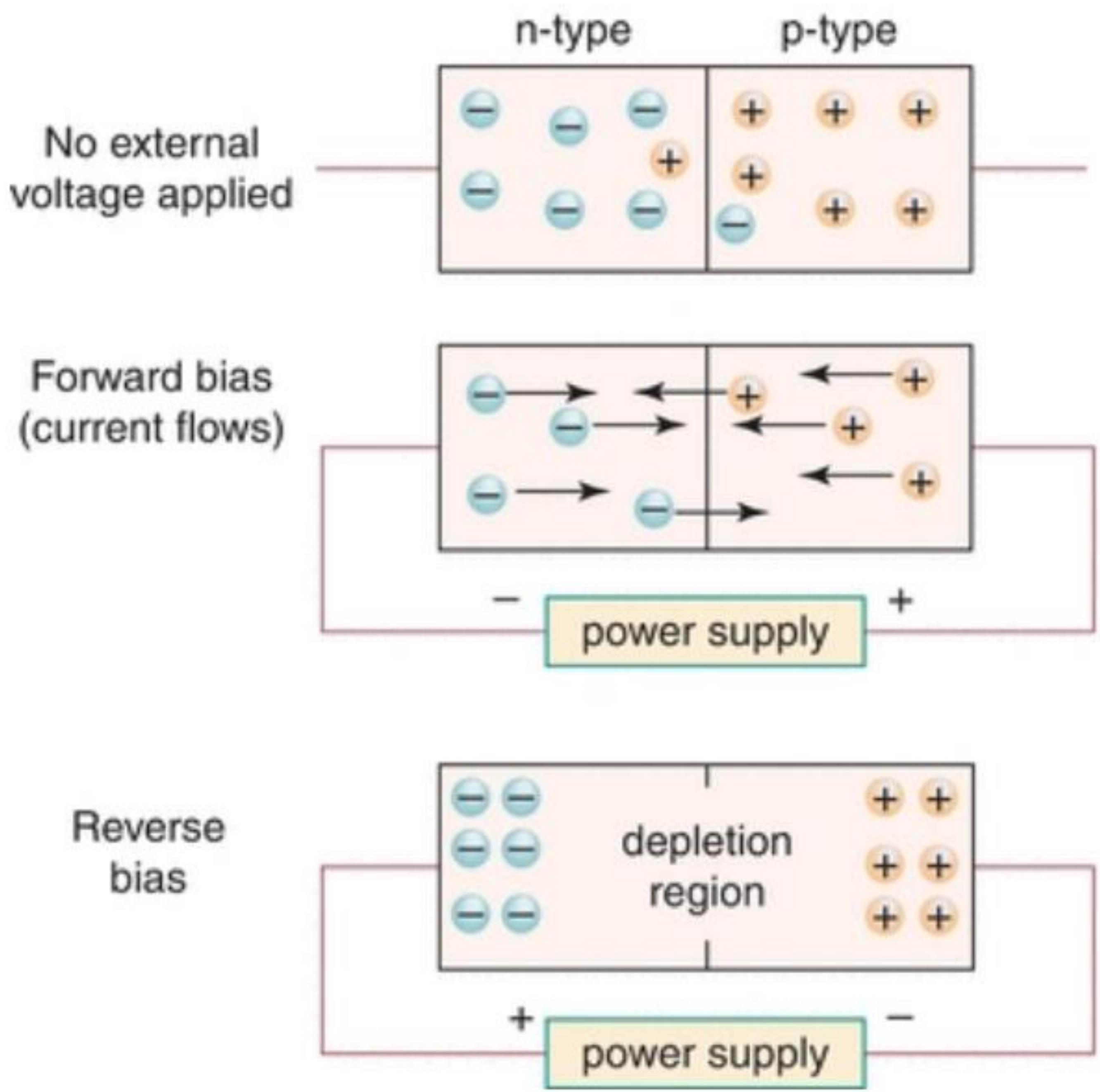
- Doping the silicon with impurities (boron, phosphorus) creates charge carriers
- One side of the diode is doped with boron which has more valence electrons than the silicon (**n-type**); the other side is doped with phosphorus which act like electron sinkholes (**p-type**)
- If we apply a voltage, fun things happen:
  - **Forward Bias**: we see **constant** current flow
  - **Reverse Bias**: we see next to **zero** current flow (DESIREABLE)
- The reverse bias allows us to see energy deposition from ionizing radiation as the signal is no longer drowned out by the noise caused by forward bias or no bias



p-type material



n-type material


n-type
p-type
No external voltage applied
Forward bias (current flows)
−
+
power supply
Reverse bias
depletion region
+
−
power supply

Types of Semiconductor Detectors

Photodiodes
(Fluoroscopy)

Liquid Nitrogen-Cooled Germanium
(Nuclear Medicine)

Cadmium Zinc Telluride [CZT]
(Nuclear Medicine)

Flat Panel Displays
(Mammography, some Radiology?)

Diodes and MOSFETs
(Therapy)

Photodiodes

Ubiquitous and cheap

Converts visible light into electrical signals

DOES NOT DETECT RADIATION

Used in scintillators to convert scintillated light into a digital signal

Liquid Nitrogen-Cooled Germanium

Very expensive and limited scope of use

Great energy resolution

Used for identifying individual gamma emitters in mixed radionuclide samples

CZT

We have one now!

Used in nuclear medicine imaging as an alternative to scintillators and germanium

Operated at room temperature

Flat Panel Displays

Amorphous selenium is often used in radiology and mammography

Provides a higher spatial resolution than scintillators

Everything is digital signal natively

Therapy Diodes and MOSFETS

Very small detectors, great for measuring scatter dose just outside of a beam

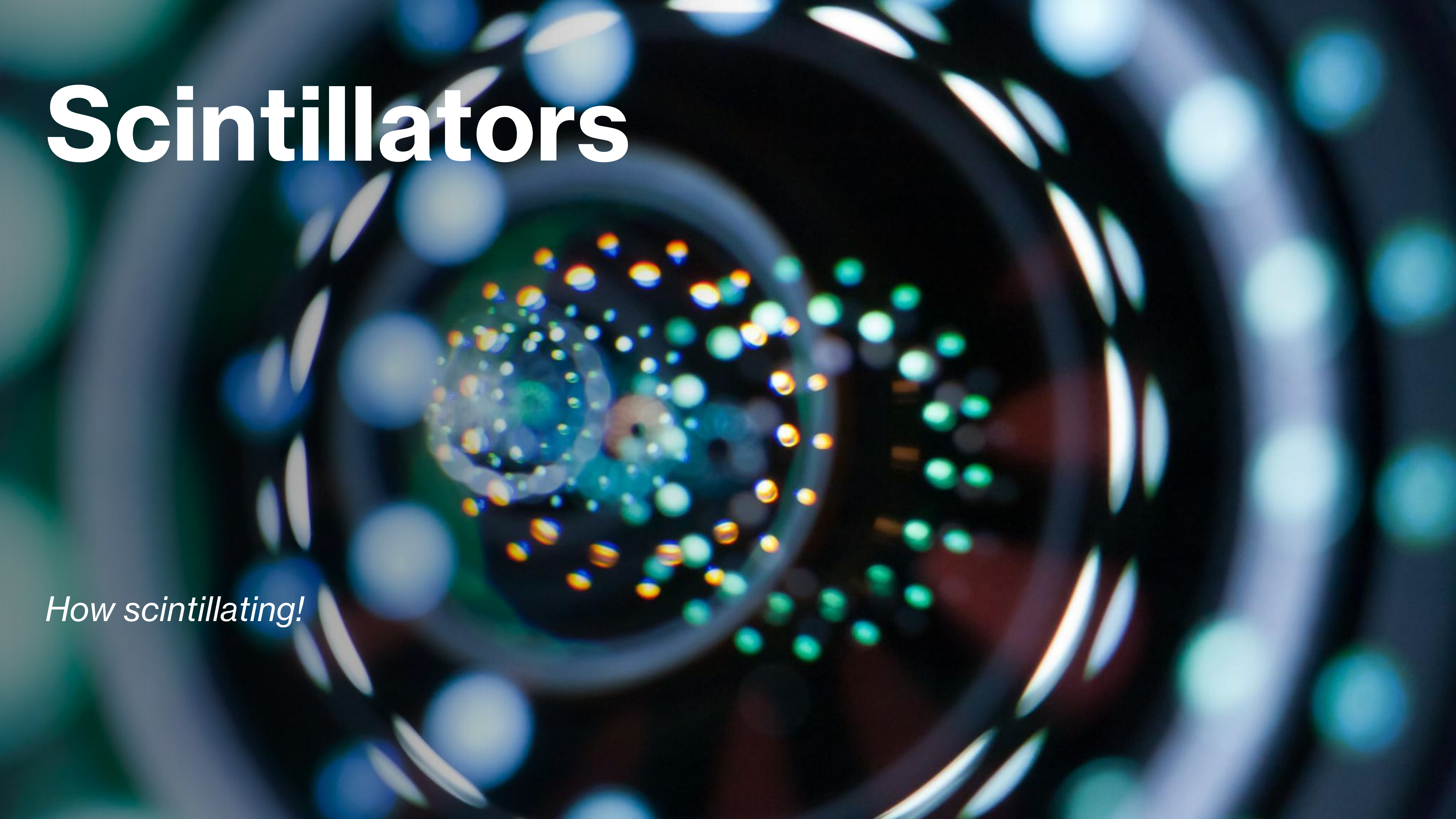
Also used for small-field dosimetry and beam characterization

Supplements ionization chambers, does not replace them

MOSFETs are very similar to diodes, the added complexity is not useful here

Scintillators

How scintillating!



Scintillator Operation

Scintillators emit visible light or UV radiation after ionization from radiation

The emitted light can be seen with the naked eye, but is often amplified

Many types and kinds of scintillation, know that plastic (organic) and some metals (inorganic) are the most common categories

Inorganic scintillators often require impurities (doping), but they are better at detecting photons

Common Nuclear Medicine Scintillators

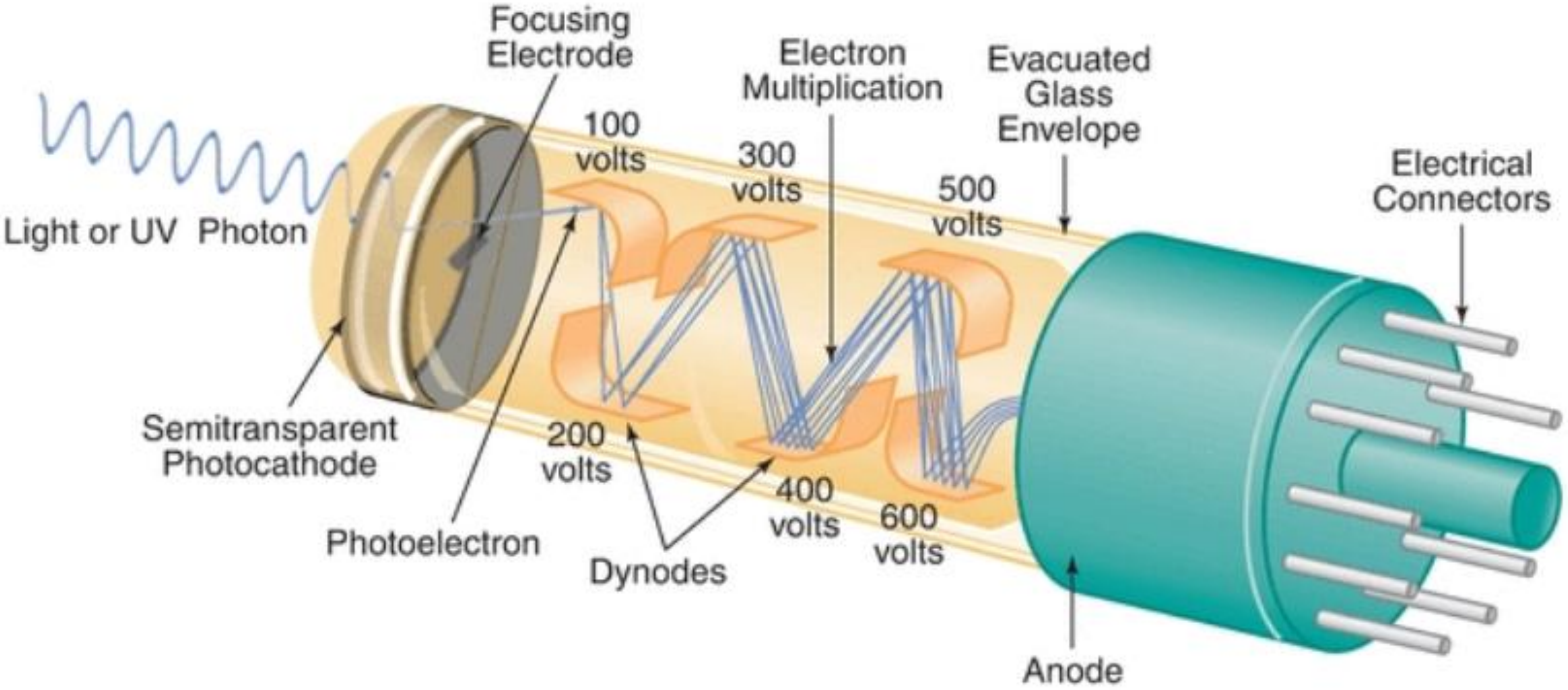
- BGO
- LSO
- NaI (Tl)
- GSO
- YSO
- BaF2
- LYSO
- LaBr3
- GAGG

Property	NaI (Tl)	BGO	GSO	LSO	LYSO	$LaBr_3$	GAGG
Chemical Formula	NaI	$Bi_4Ge_3O_{12}$	Gd_2SiO_5	Lu_2SiO_5	$Lu_{2(1-x)}Y_{2x}SiO_5$	$LaBr_3$	$Gd_3(Ga,Al)_5O_{12}$
Z_{eff}	51	74	59	66	60	47	48
Density (g/cm^3)	3.67	7.13	4.89	7.4	7.2	5.3	6.63
Light output (ph/keV)	41	9	10	31	30	67	54
Wavelength (nm)	410	480	440	420	420	370	540
Decay time (ns)	230	300	60	40	41	25	94
Hygroscopic?	Yes	No	No	No	No	Yes	No

Photomarkiplier Tubes

- Photomultiplier tubes capture light, convert it into electrical signal, then amplify the electrical signal
- Extremely high-voltage
- Very large
- Often used in nuc. med.

$$5 \times 5 \times 5 \times 5 \times 5 \times 5 \times 5 \times 5 \times 5 \times 5 = 5^{10} \approx 10,000,000.$$



Scintillator + Photodiode

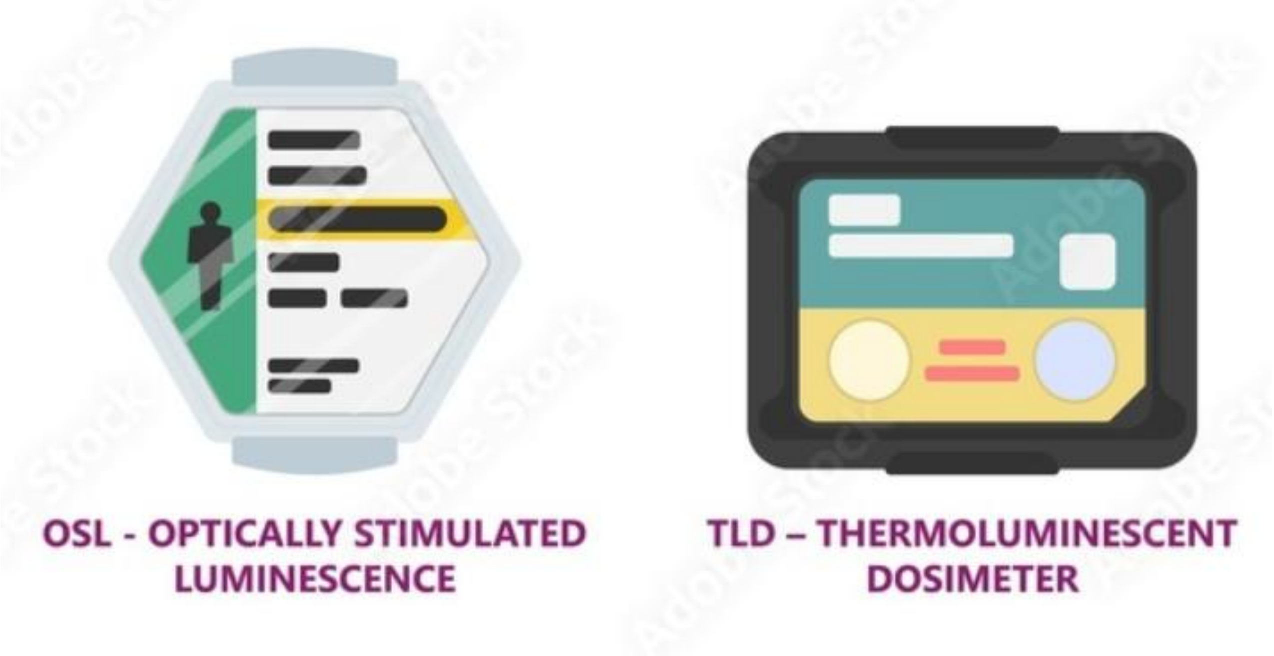
Photodiodes may be used instead of PMTs

Used in many CT scanners and in-direct thin-film transistor mammography/radiology detectors

Light emitted from scintillator is captured by photodiodes and converted into electrical signal

Trapping Scintillators

- These scintillators trap excited electrons, which can be released later
- Two main types,
  - Thermoluminescent Dosimeters [TLDs]
  - Optically Stimulated Luminescent Dosimeters [OSLDs] (now mostly defunct in therapy, but making a comeback)




Film
Spooky ahh image

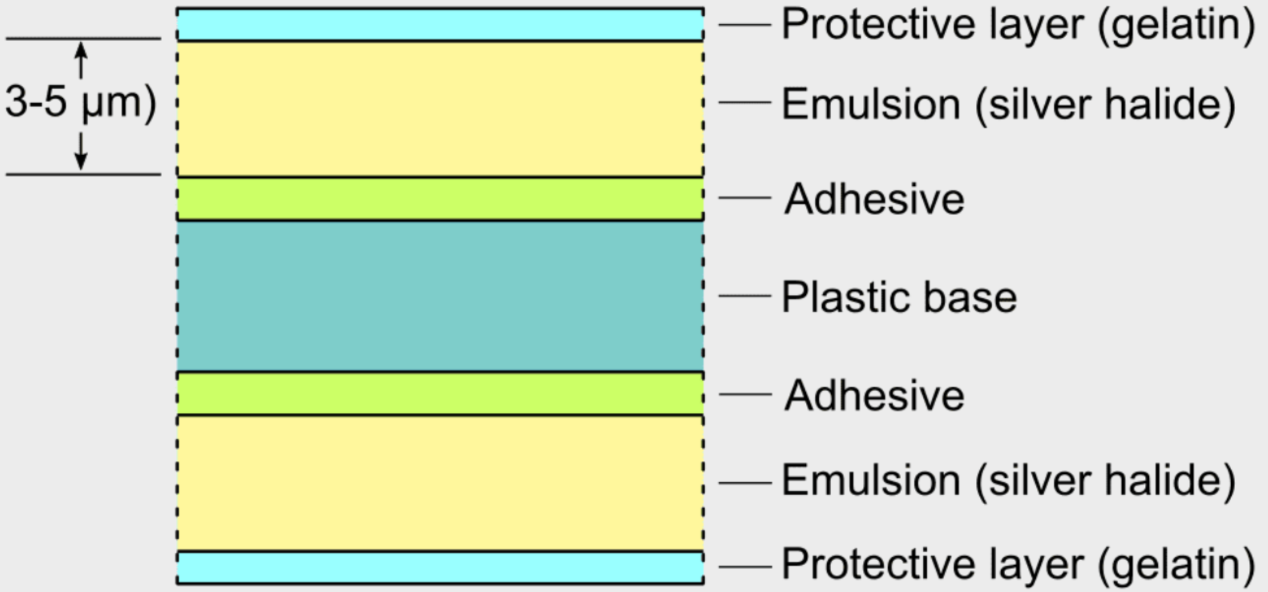
Motivation of Film

- Permanent record
- Great spatial resolution
- Provides planar views of linac beams
- Inexpensive in the short-term
- Do not require electricity to use! (Developing Countries)

Types of Film

- Radio***graphic***
  - Silver halide crystals in an emulsion are ionized which darkens produces an image when processed
  - Requires careful processing in a dark room with chemicals
  - AgBr is fixed and the irradiated Ag is washed away?
  - High average Z is not great, and developing film really sucks
- Radio***chromic***
  - Better than radiographic!
  - Self-developing
  - Starts as light green, becomes darker after irradiation
  - Takes approximately 24 hours to finish darkening
  - GafChromic is the name-brand

Radiographic Film Contrsuction



Radiochromic Film Construction