Film Dosimetry

Introduction

Introduction

In the United States, three types of dosimeters can be used to measure the “dose of record:”

- Film
- Thermoluminescent dosimeters
- Optically stimulated luminescent dosimeters

Introduction

Film dosimeters are most commonly employed to evaluate personnel exposures to x-rays.

Hence, film dosimetry is often used in dentistry, veterinary practice, medicine and universities.

Introduction

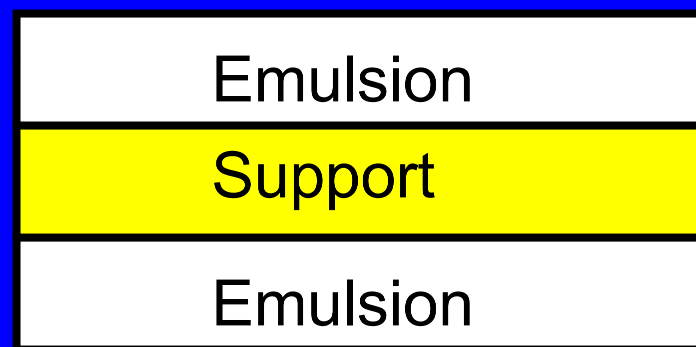
Over time, an exposure to light or ionizing radiation can change the color of some materials.

Silver bromide is very susceptible to this phenomenon. The exposure to light or ionizing radiation changes the silver bromide, a yellow-white salt, to metallic silver which is black.

Certain chemicals can speed up (catalyze) this color change.

Introduction

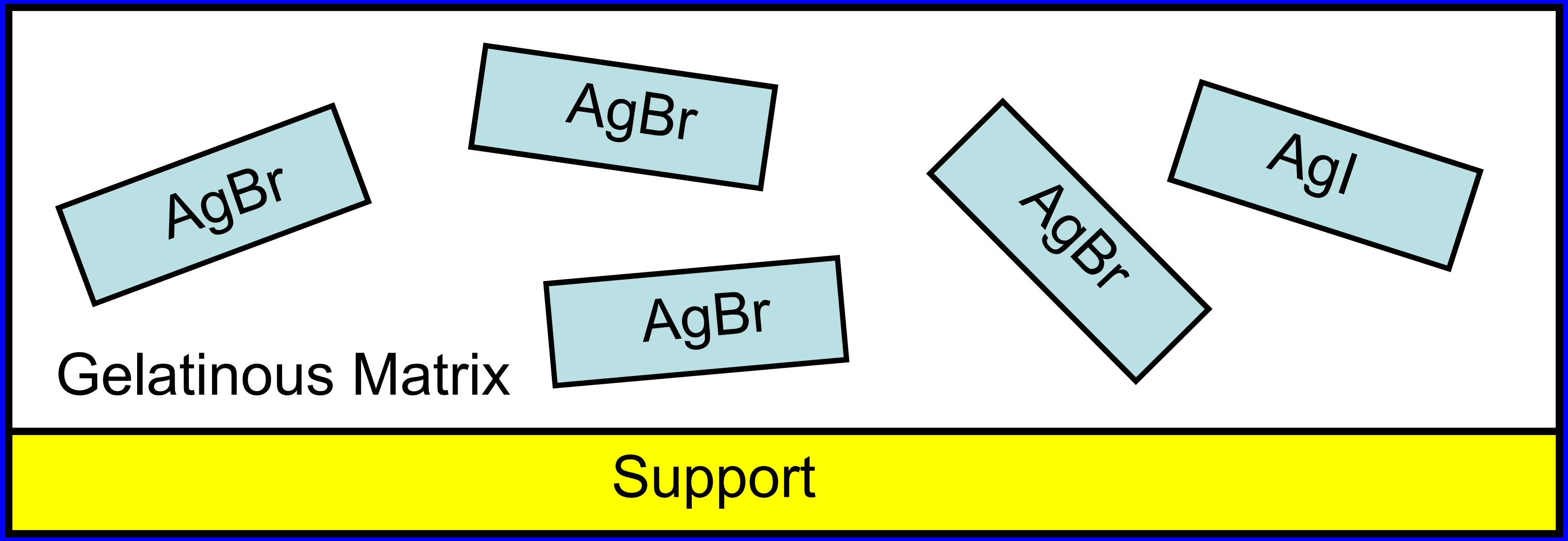
SINGLE
EMULSION



DOUBLE
EMULSION

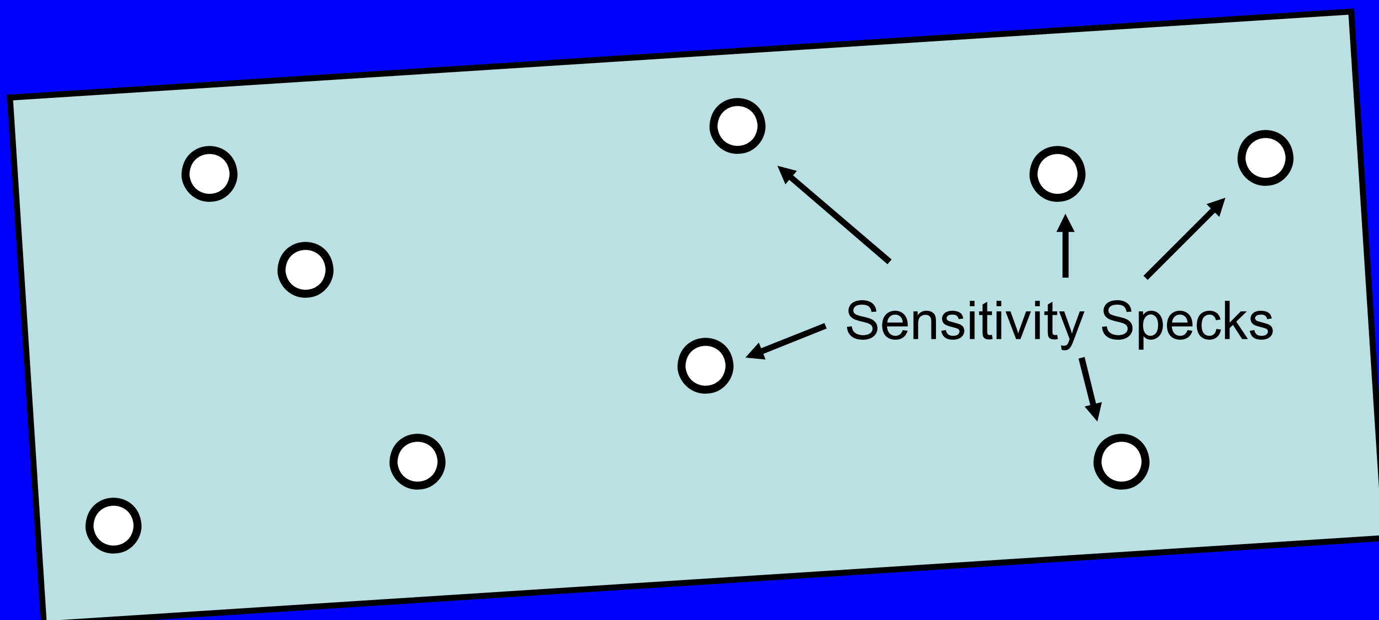
Introduction

The emulsion consists of a gelatinous matrix in which silver bromide (AgBr) crystals are suspended. The properties of the film depend on the size (ca. 1 um), shape, and number of these crystals (ca. 6 x 10^9 AgBr grains per cc). Some silver iodide (AgI) crystals are also present.



Introduction

The silver bromide crystals have defects that contain groups of positively charged silver ions (Ag+). We will refer to these as "sensitivity specks."

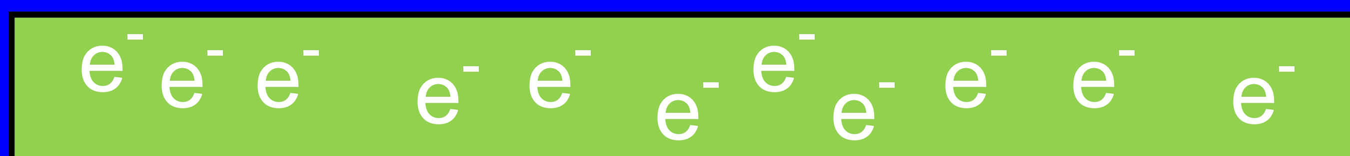


SILVER BROMIDE (AgBr) CRYSTAL

Introduction

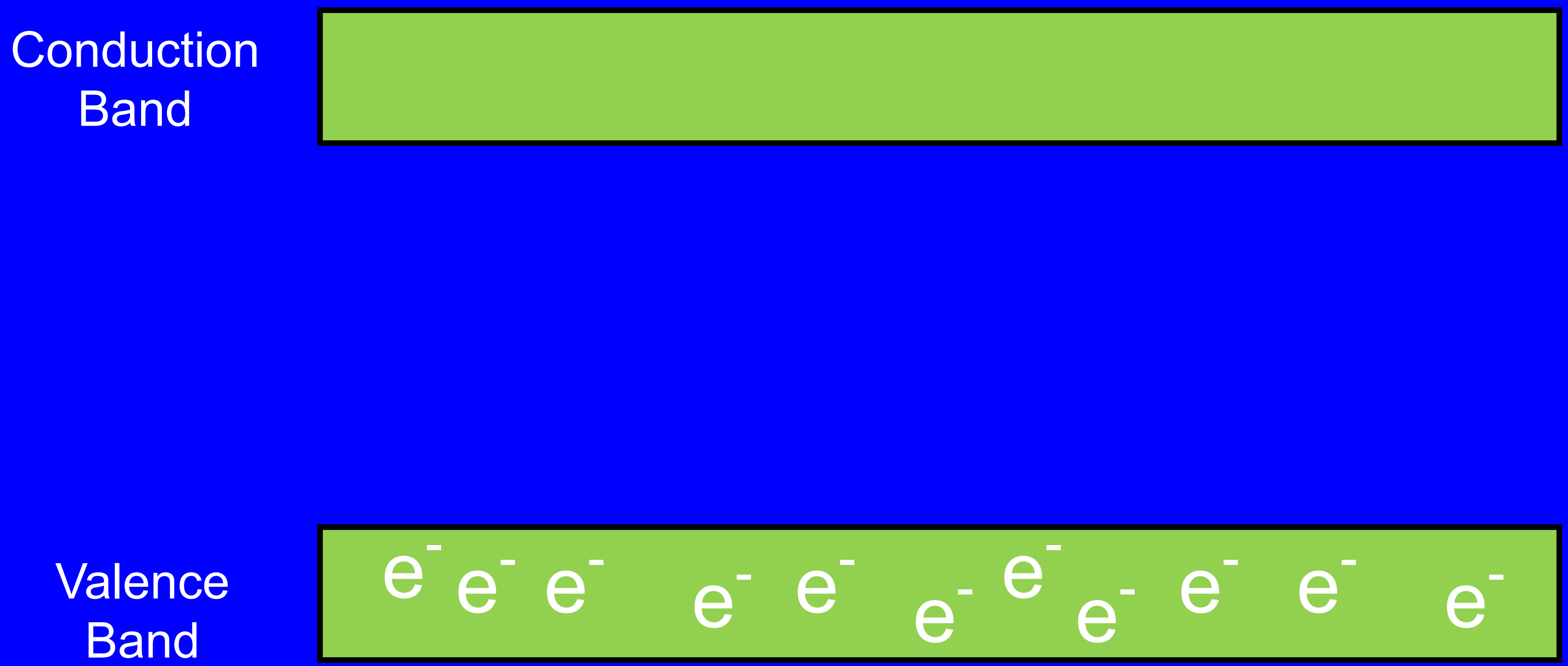
The highest energy electrons in the silver bromide crystal occupy a range of energies known as the Valence Band.

Valence Band



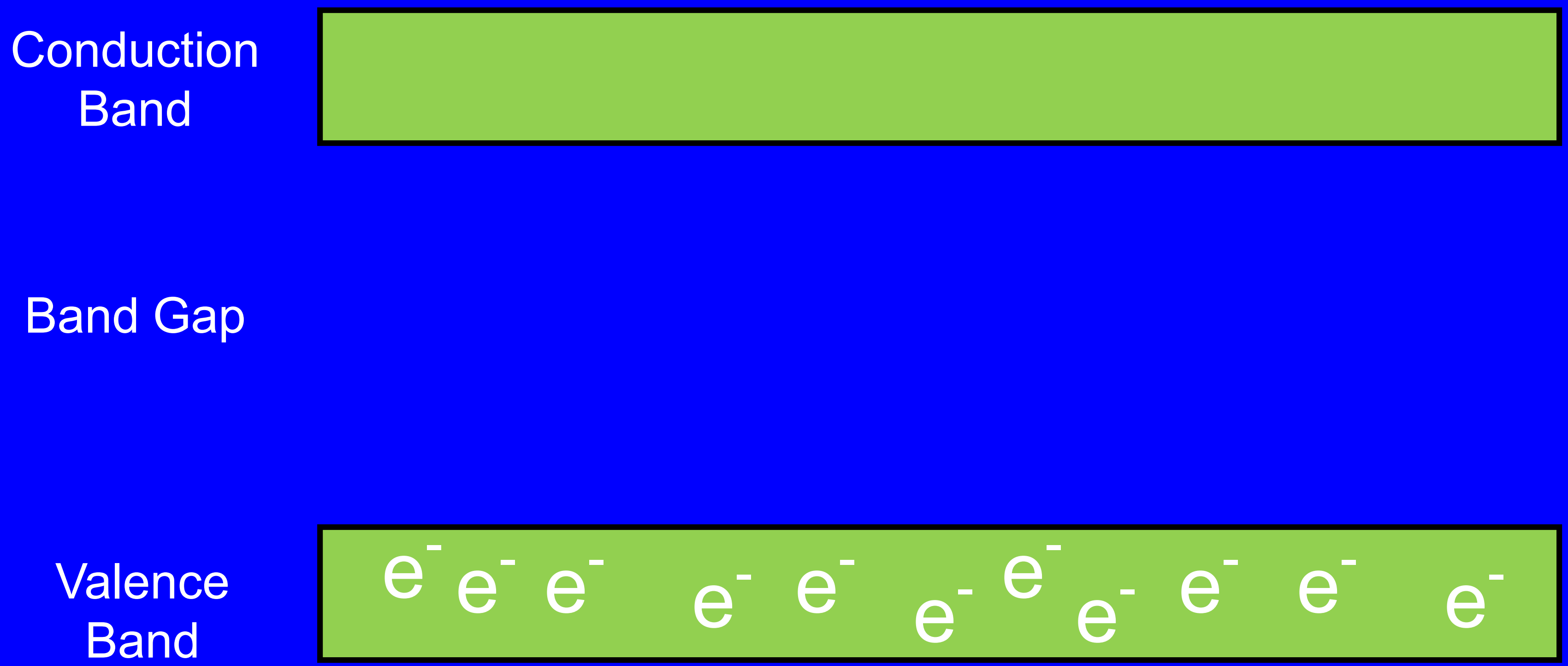
Introduction

The conduction band is a higher energy level normally empty of electrons. If an electron were in the Conduction Band, the electron would be mobile.



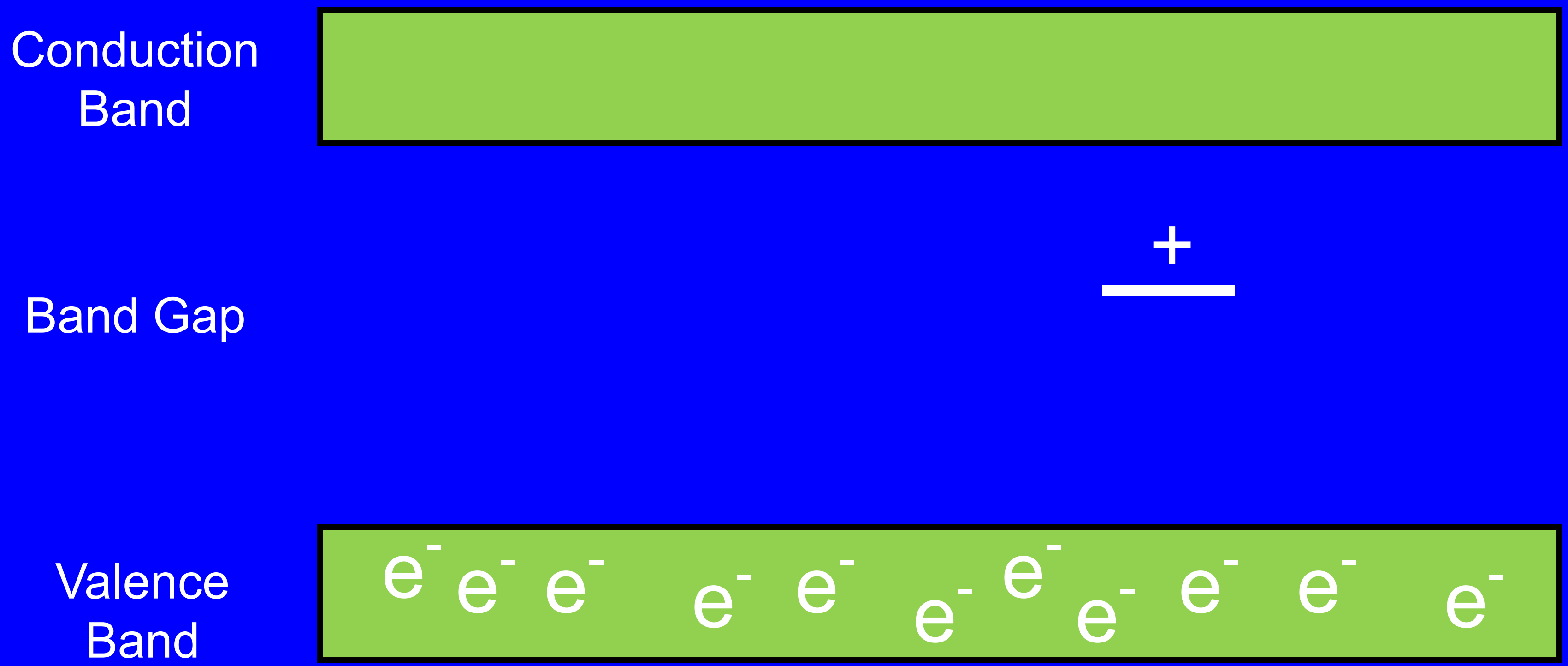
Introduction

The range of energies between the Valence and Conduction bands is the Band Gap. If the crystal were pure, electrons could not occupy the Band Gap.



Introduction

A sensitivity speck (a group of Ag+ ions) has electron vacancies. If an electron filled one of these vacancies, it would have an energy in the Band Gap.



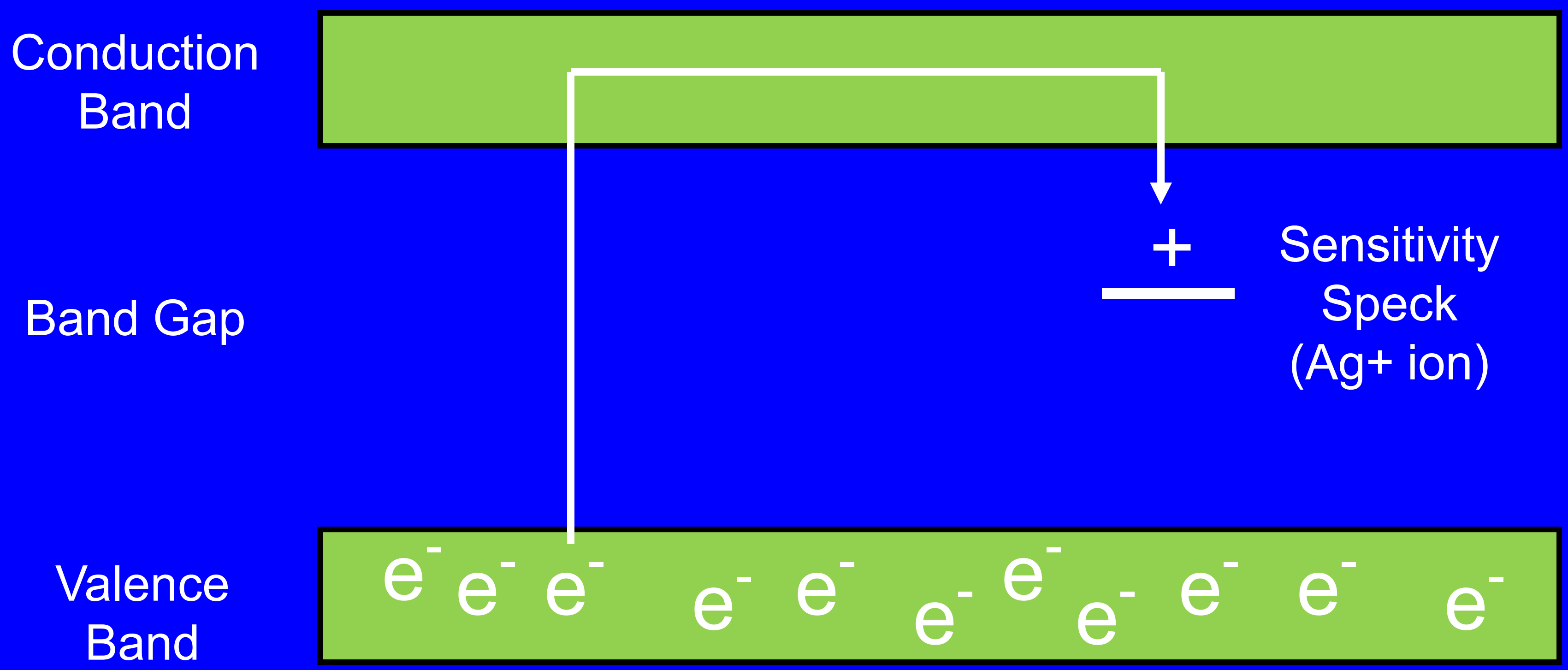
Introduction

When radiation energy is absorbed by a silver bromide crystal, some of the electrons are promoted from the Valence Band to the Conduction Band.

Once in the Conduction Band, these electrons are mobile. Some will move to the sensitivity specks and fill the electron vacancies.

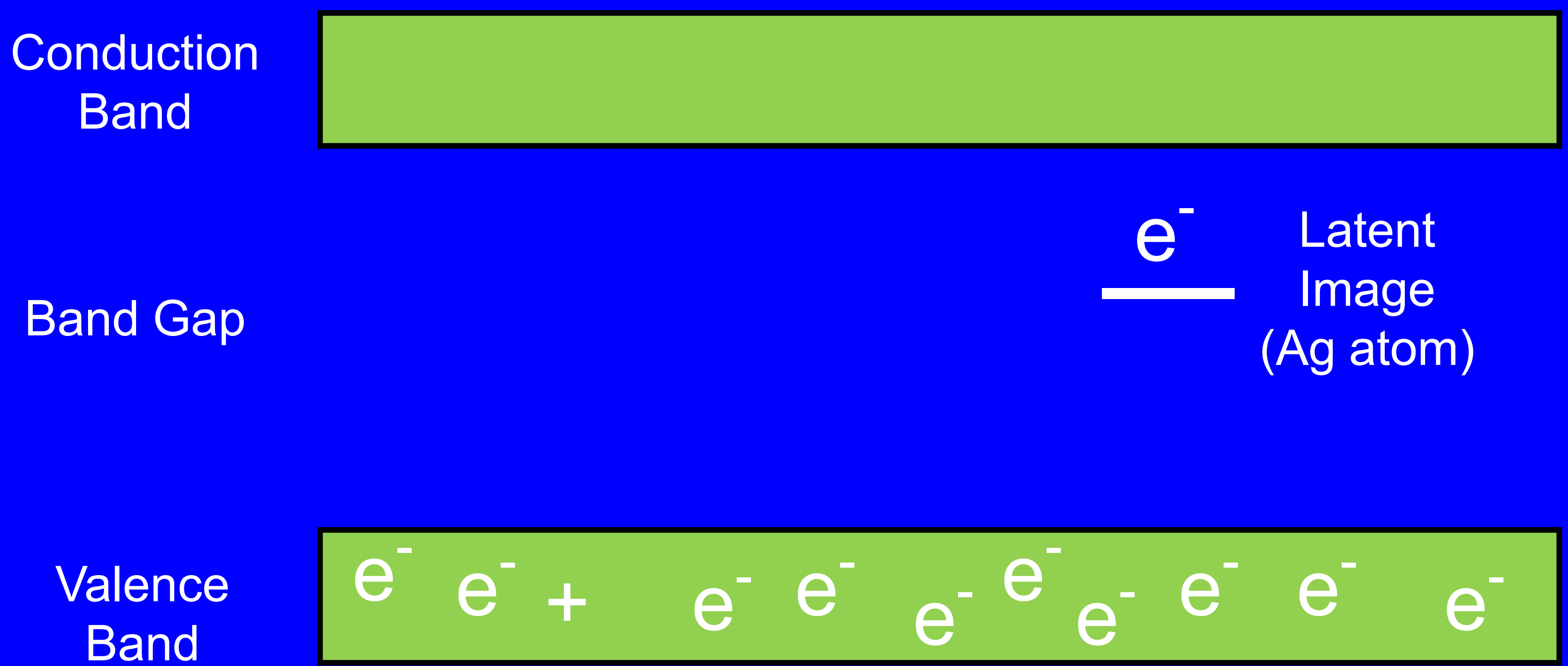
Introduction

As a result of an exposure to radiation, an electron in the Valence Band is promoted to the Conduction Band.



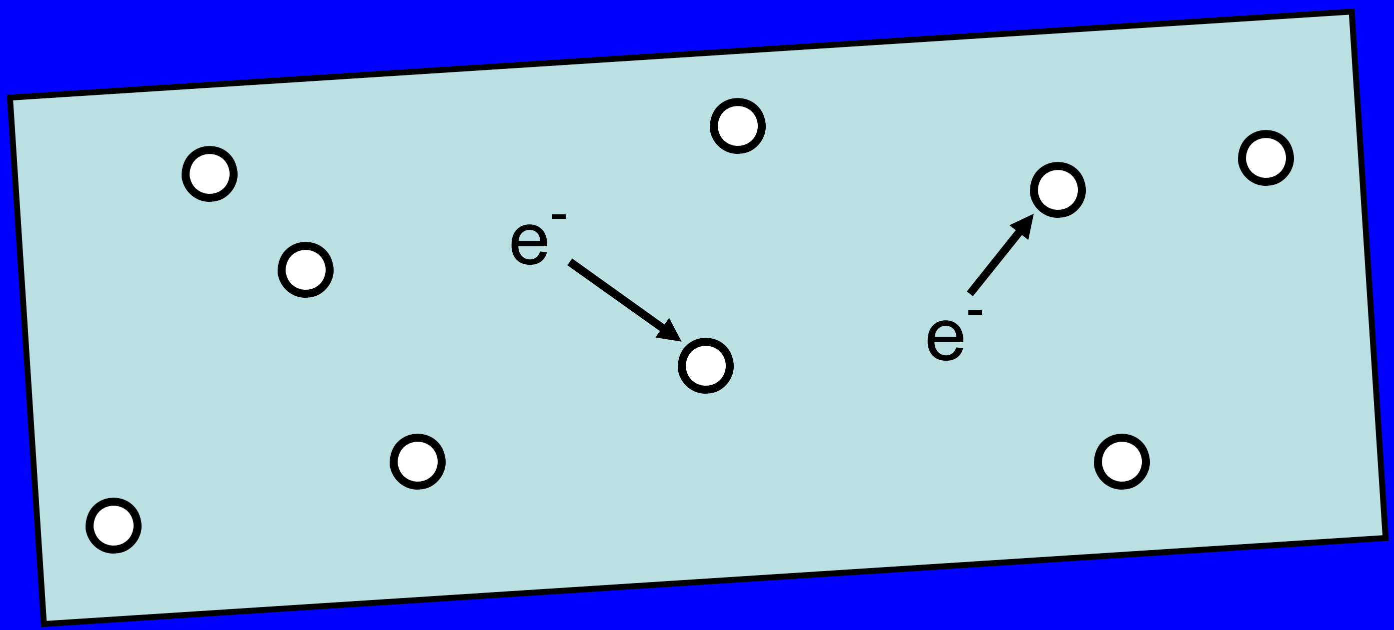
Introduction

If an electron reaches a “sensitivity speck” the latter is converted into a “latent image” that consists of neutral silver atoms, i.e., silver metal.



Introduction

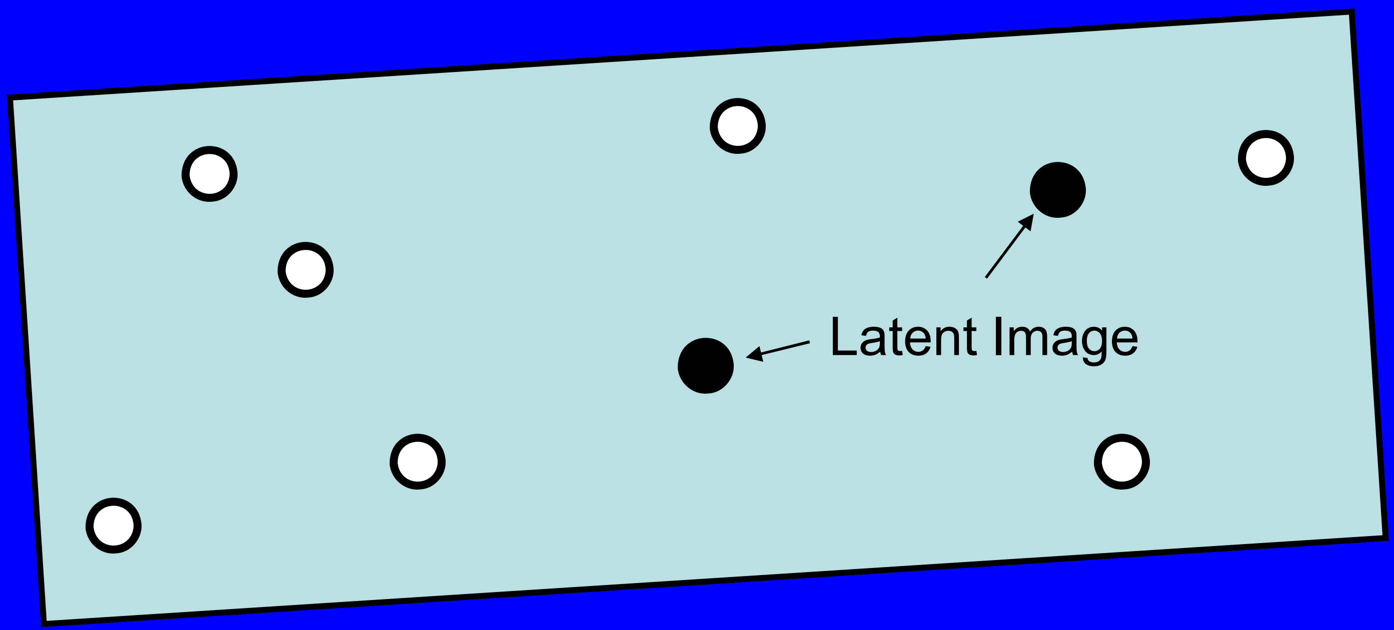
This shows two electrons moving to "sensitivity specks." The greater the radiation energy deposited in the crystal, the greater the number of electrons moving to the sensitivity specks.



SILVER BROMIDE (AgBr) CRYSTAL

Introduction

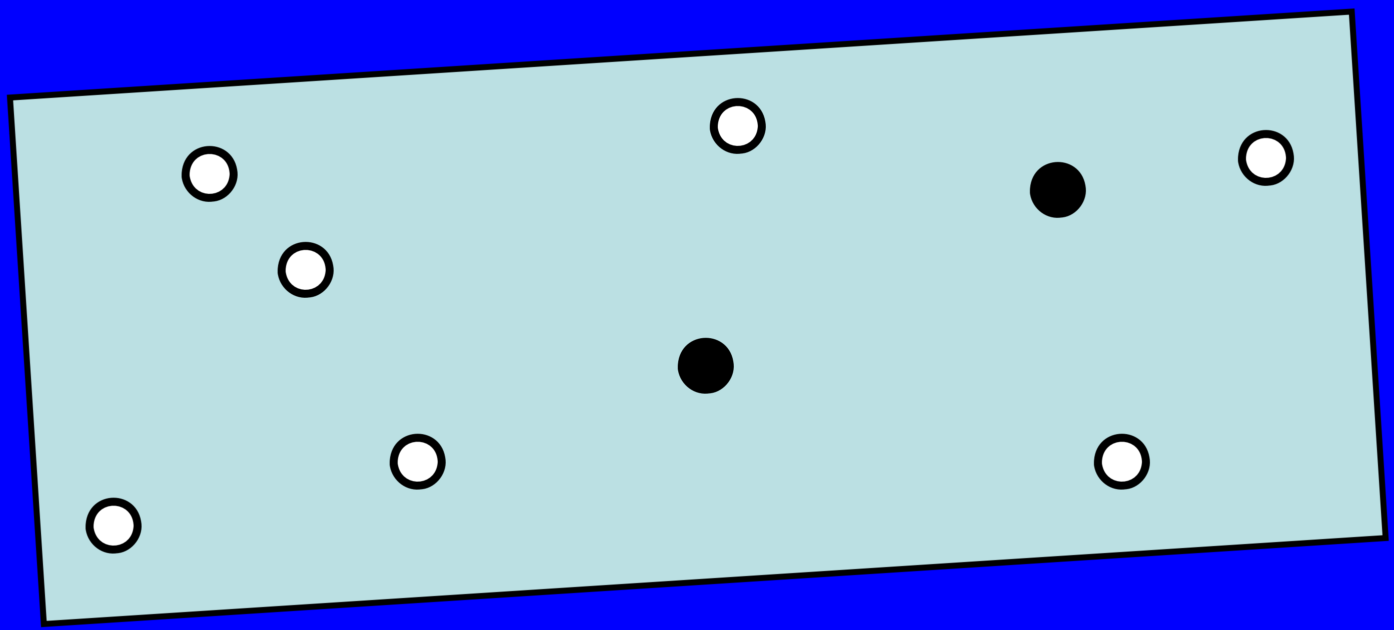
Two sensitivity specks have now been converted to "latent images."



SILVER BROMIDE (AgBr) CRYSTAL

Introduction

The silver ions at the latent image have been chemically reduced, i.e., converted to metallic silver.



SILVER BROMIDE (AgBr) CRYSTAL

Film Processing

Film Processing

After it has been exposed to radiation, the photographic film is processed.

The processing consists of three or four steps:

1. Submersion of the film in a developing solution
2. Submersion of the film in a stop bath
3. Submersion of the film in a fixative solution
4. Rinsing the film in water.

Developer

The developer solution contains chemicals that speed up the reduction of the silver bromide.

If the radiation produced 10 or so atoms of metallic silver (reduced Ag+ ions) in a crystal, the developer can catalyze the complete conversion (reduction) of the AgBr crystal into a grain of metallic silver.

Each interaction of a 10 keV photon might produce one “developable crystal. The interaction of a 1 MeV photon might produce 5-10 “developable” crystals.

Stop Bath (optional)

The stop bath, usually a solution of dilute acetic acid, accomplishes two purposes:

- It stops the action of the developer
- It minimizes the contamination of the fixative by the developer

Fixative

The purpose of the fixative (containing sodium thiosulfate) is to dissolve any remaining unreduced silver bromide crystals. Unless this is done, the film would darken following a subsequent exposure to light. As the name implies, the fixative stabilizes the “image.”

Once the film is in the fixative, it can be exposed to ambient light.

As a rule, used fixative is collected so that the silver can be recycled.

Rinse

The purpose of the rinse (e.g., 30-40 minutes in running water) is to remove the fixative solution.

After rinsing, the film should be dried in such a way as to avoid drying spots.

Quality Control

To ensure a consistent relationship between the darkening of the film and the absorbed dose:

- The times that the film is in the developer (e.g., 10 min) and fixer (e.g., 10-15 min) must not change.
- The temperature of the developer (e.g., 20 ºC) must be consistent.
- The developer and fixer solutions should be fresh.
- Agitation of the film during developing (e.g., a few seconds every minute) should be consistent.

Assessing the Dose

Assessing the Dose

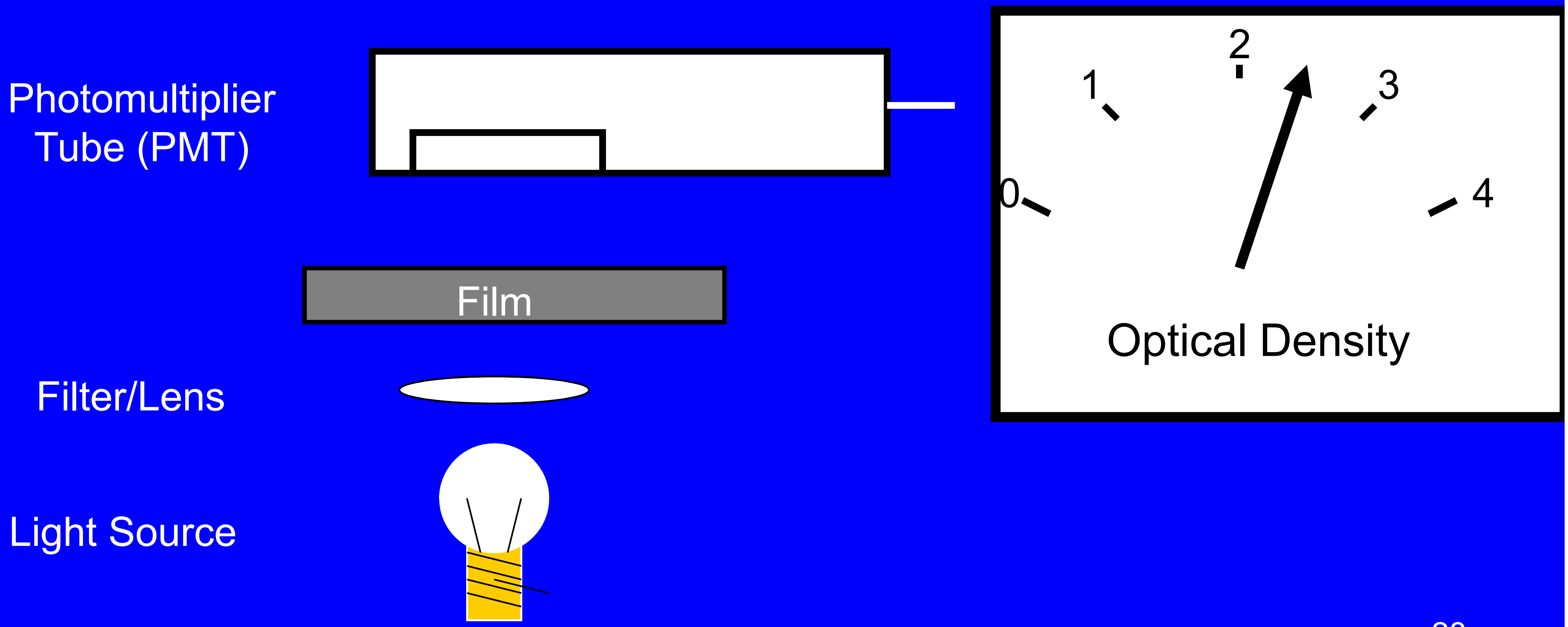
The greater the radiation dose, the darker the film will be after processing.

Until the 1950s, the darkening of the film was often assessed by eye. One procedure was to try to read a newspaper through the processed film. If the newspaper could be read, the dose was considered acceptable.

In the mid 1940s, electronic instrumentation (densitometers) began to be used to quantify the darkening of the film.

Densitometer

A densitometer is a device that is used to measure the darkening of the film. The following diagram illustrates a typical densitometer.



Densitometer

A photomultiplier tube is used to measure the amount of light that gets through the film.

The process involves comparing the intensity of the light that gets through the exposed film with the intensity of light that gets through unexposed film.

The densitometer reads out in units of “optical density” which ranges from 0 to 4 or so.

Optical Density

The "optical density" is calculated as follows.

$$O.D. = \log\left(\frac{I_0}{I_x}\right)$$

O.D. is the "optical density"

I_0 is intensity of light that gets through unexposed film

I_x is intensity of light that gets through the exposed film

Optical Density

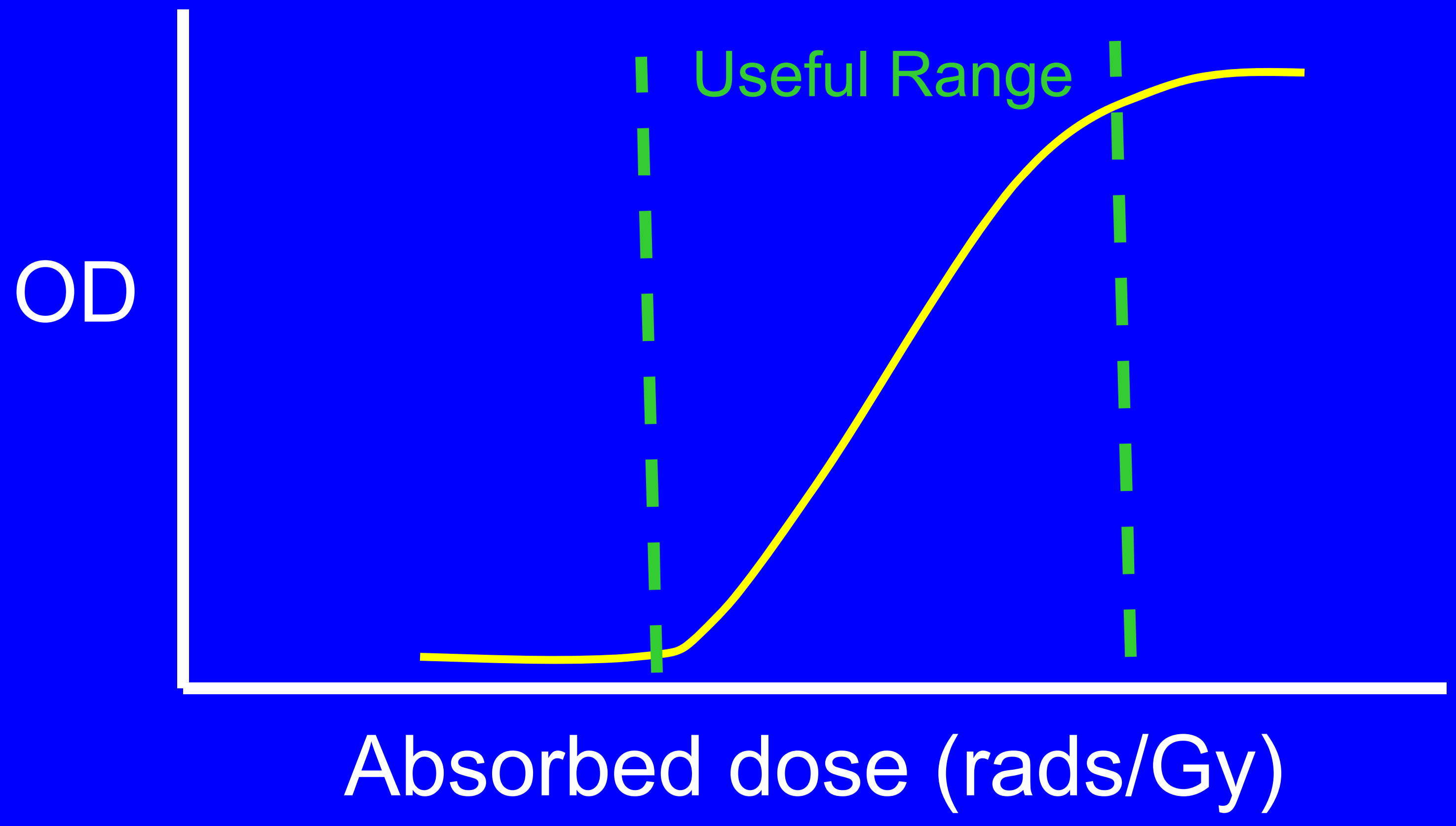
If ten times more light gets through the unexposed film than gets through the exposed film, the optical density is 1.

If one hundred times as much light gets through the unexposed film as gets through the exposed film, the optical density is 2.

If one thousands times as much light gets through the unexposed film as gets through the exposed film, the optical density is 3.

Calibration Curve

The optical density of film exposed to different doses is measured. Optical density is the plotted as a function of absorbed dose.



Calibration Curve

The optical density of an emulsion for a given exposure (the sensitivity) depends on several things:

– Thickness of emulsion

– Density of AgBr crystals

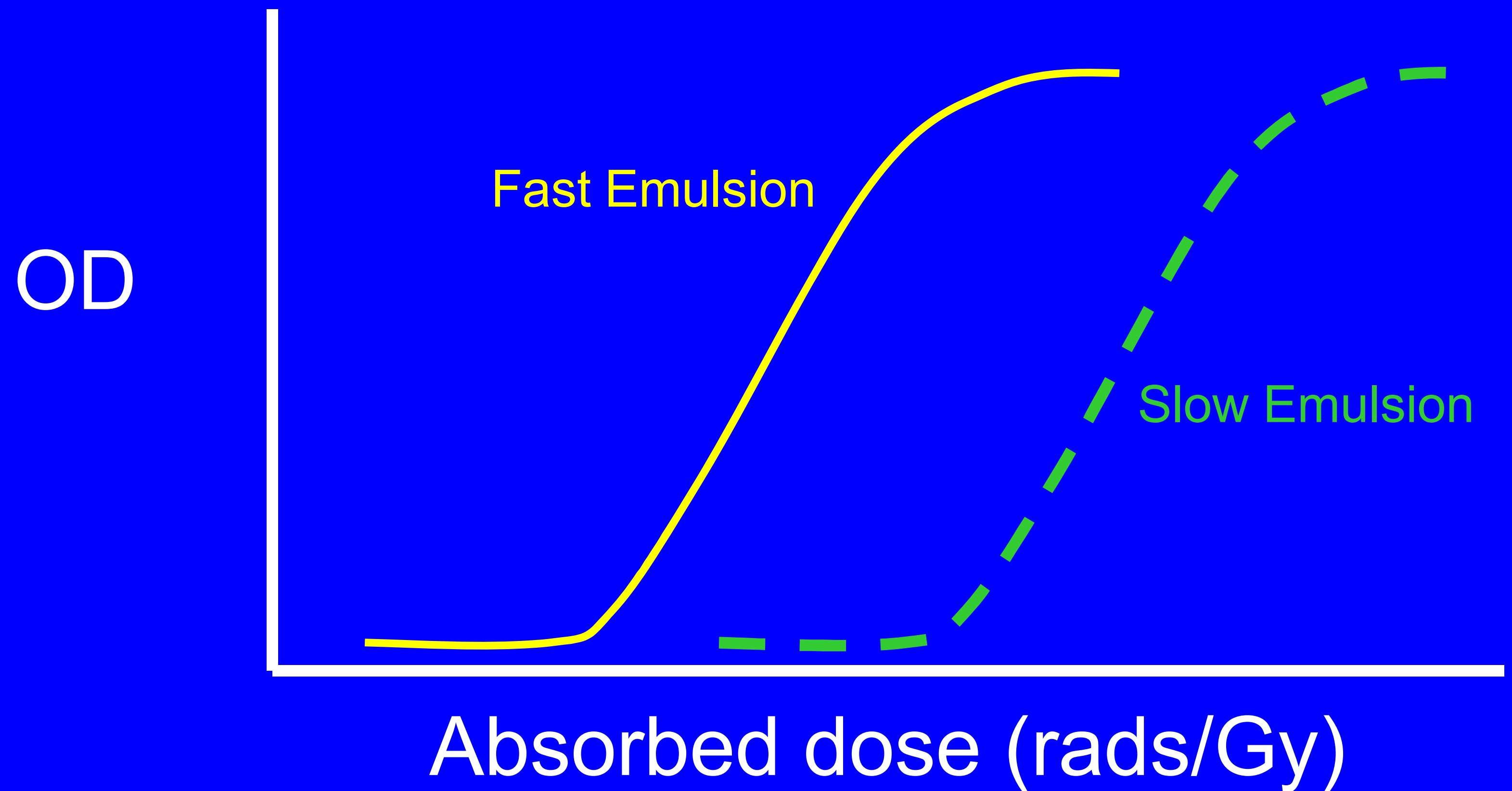
– Density of AgI crystals

– Size and shape of crystals (grains)

– Nature of defects/impurities in crystals

Calibration Curve

A high sensitivity emulsion, known as a "fast emulsion," is better able to assess low doses. A low sensitivity emulsion, known as a "slow emulsion," is better able to assess high doses.



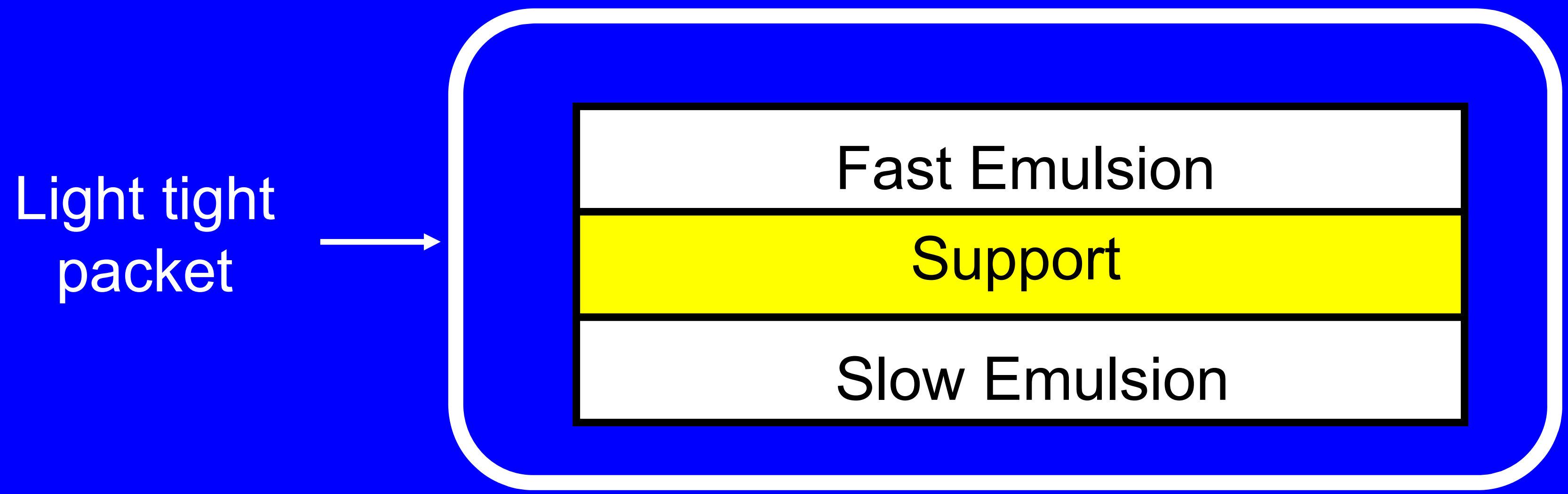
Kodak Film Types for Therapeutic Radiology

Film Type	Range	Saturation
PPL	0.25 – 5 rads (0.0025-0.05 Gy)	10 rads (0.1 Gy)
XTL	1 – 15 rads (0.01-0.15 Gy)	30 rads (0.3 Gy)
XV-2	5 – 100 rads (0.05-1 Gy)	200 rads (2 Gy)
EDR2	25 – 400 rads (0.25-4 Gy)	700 rads (7 Gy)

Kodak Film for Personnel Monitoring

Kodak Type 2 Film	
Approximate useful Range	30 mrems - 2500 rads
Beta Response (maximum)	1.71 – 5 MeV
Photon Response	5 keV – 3 MeV

Kodak Type 2 Film for Personal Monitoring



So that the two sides can be easily distinguished, the fast emulsion has a matte surface while the slow emulsion has a glossy surface.

Kodak Type A NTA Film for Neutrons

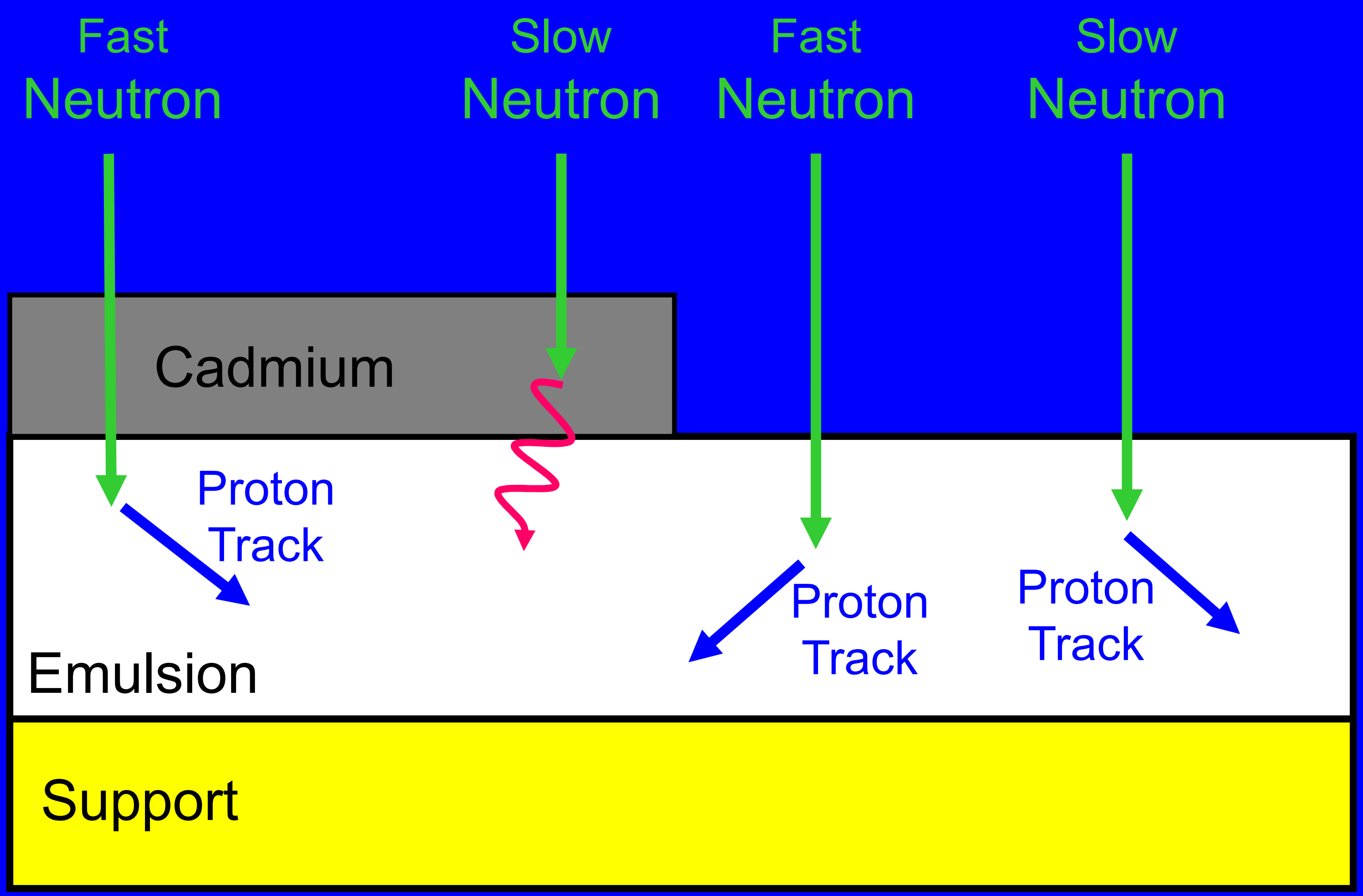
Although no longer used, this film was once commonly employed to estimate neutron doses.

Thermal neutrons were absorbed by nitrogen in the film. The resulting n, p reaction produced proton tracks in the developed emulsion.

Fast neutrons with energies above 500 keV produced tracks due to proton recoil, i.e., elastic scattering collisions with hydrogen nuclei in the film.

The film was insensitive to neutrons with epithermal energies up to 500 keV.

Kodak Type A NTA Film for Neutrons



Kodak Type A NTA Film for Neutrons

The tracks were counted under a microscope and the track density was related to the absorbed dose.

A cadmium filter was used to distinguish the number of proton tracks produced by fast neutrons from the number of tracks produced by slow neutrons.

Film Dosimeter Badges

Beta Dose

The film holder (aka badge) usually has an open “window.”

The film in the window area responds to beta particles as well as x-rays and/or gamma rays.

The film covered by the plastic film holder only responds to x-rays and gamma rays.

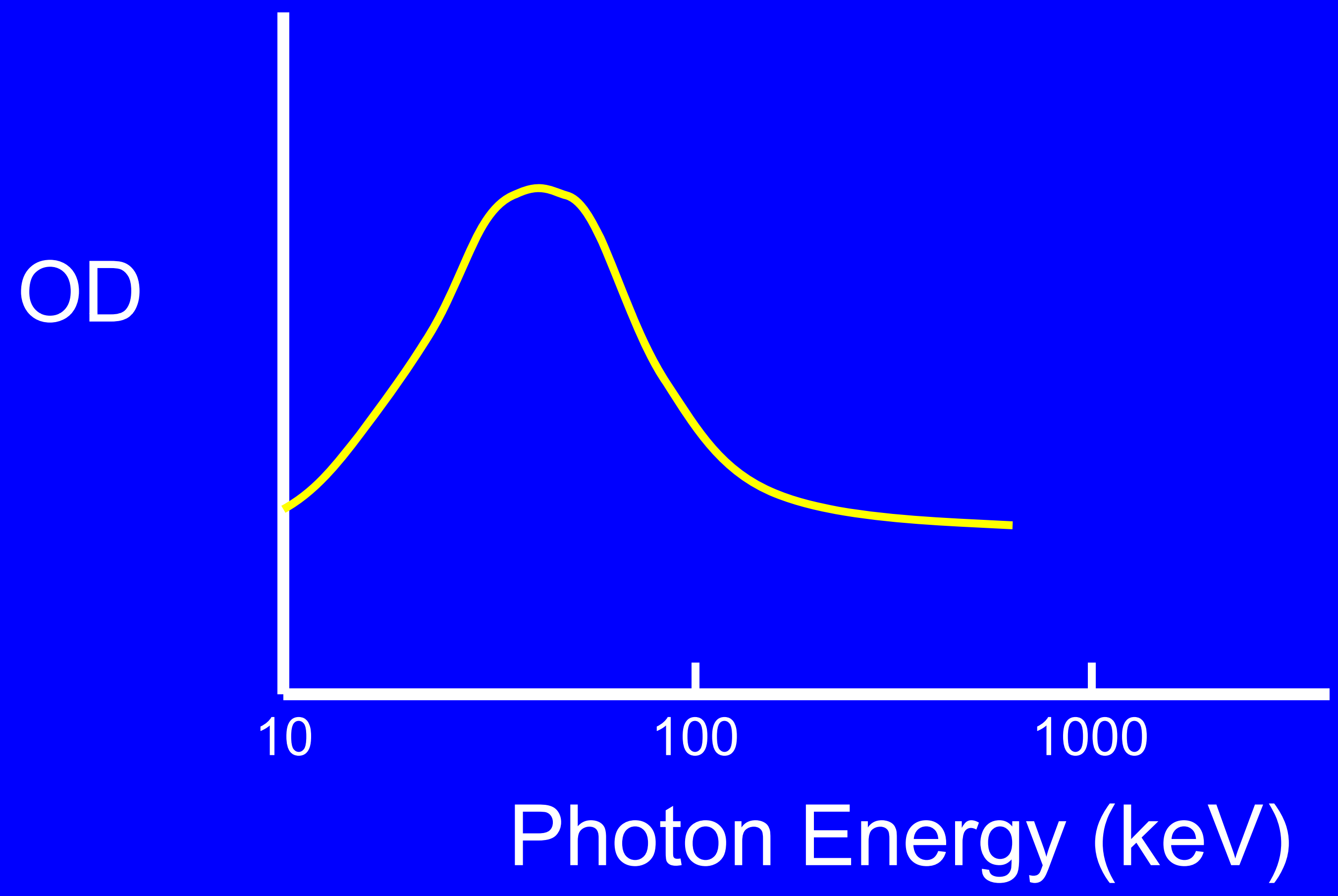
Energy Dependence of Film Response

The sensitive component of the film dosimeter, the silver bromide crystals, contains a high Z material: silver (Ag).

For a given exposure (e.g., 1 rad), the optical density is greater for low energy photons (e.g., 100 keV) than for higher energy photons (e.g., 662 keV).

Energy Dependence of Film Response

Optical density as a function of photon energy for a given exposure (e.g., 1 rad)

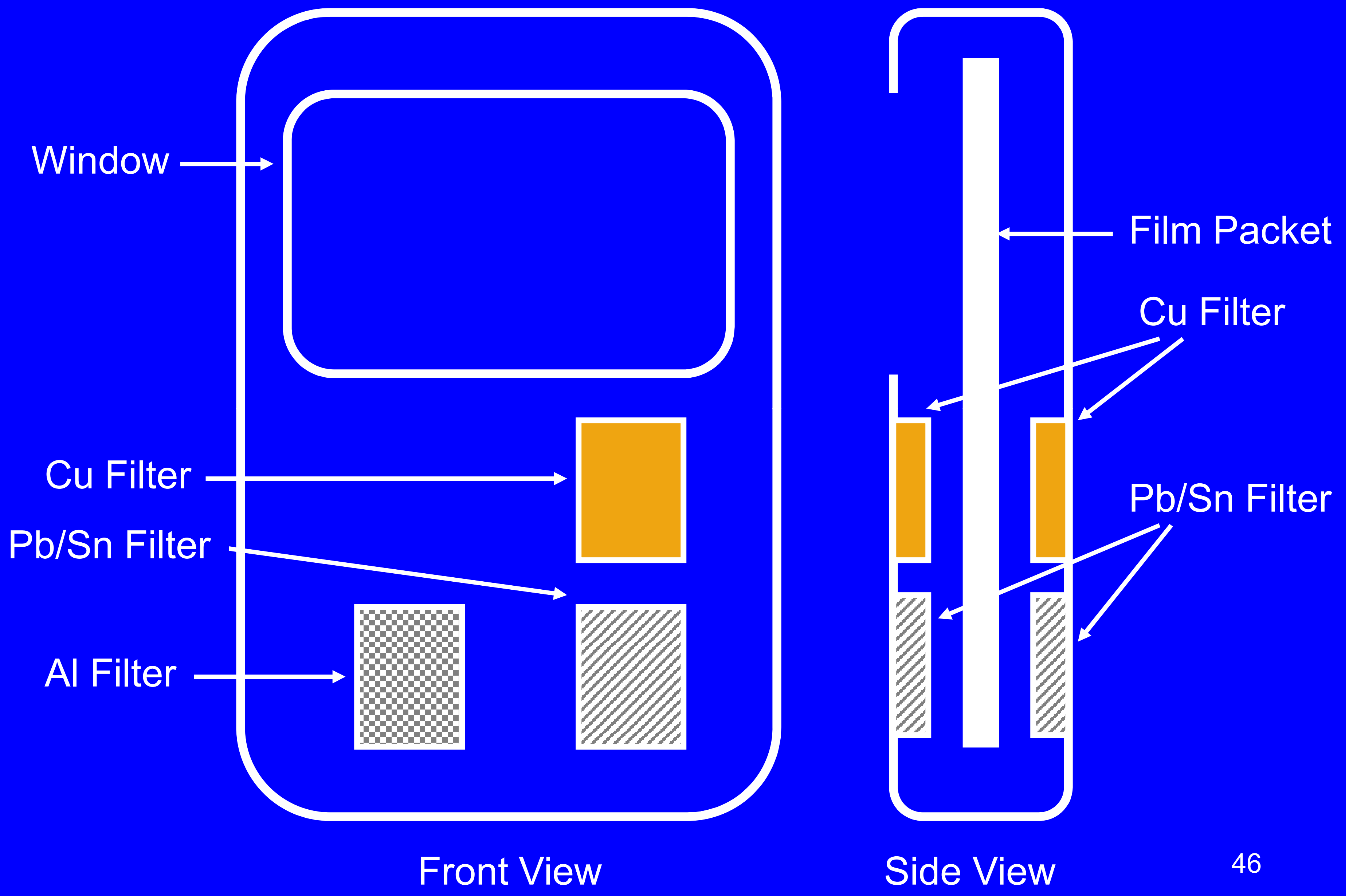


Energy Dependence of Film Response

This means that the calibration factor, which relates the optical density to the absorbed dose, varies with the photon energy. As such, film dosimeters must use some method to estimate the energy of the photons to which they are exposed.

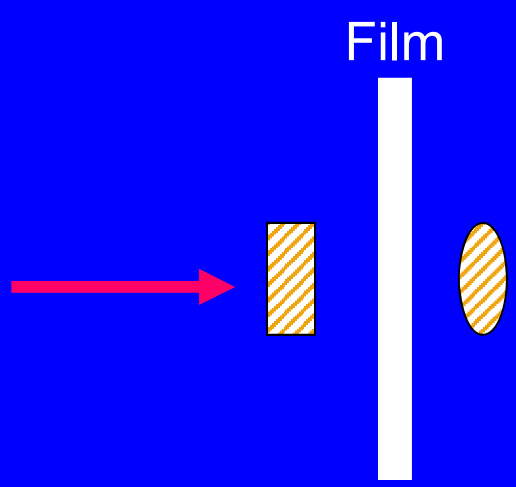
They do so by analyzing the ratios of the optical density of the film underneath metal filters with different atomic numbers (e.g., Al, Cu, Pb).

Typical Film Badge Design

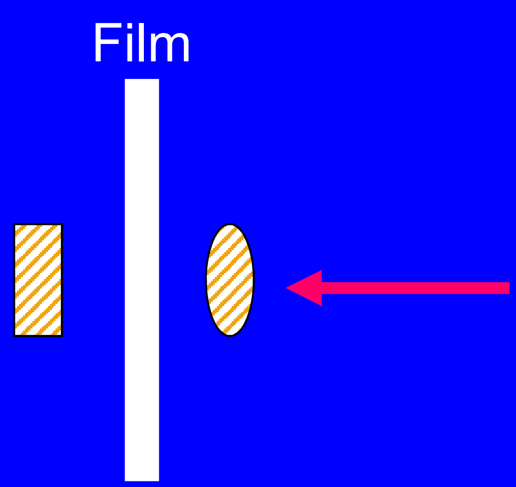


Exposure Direction

In some cases, the filters on the front of the badge and those on the back have different shapes (e.g., square vs round). In this case, the image of the filter on the developed film can identify whether the exposure was from the front or back.



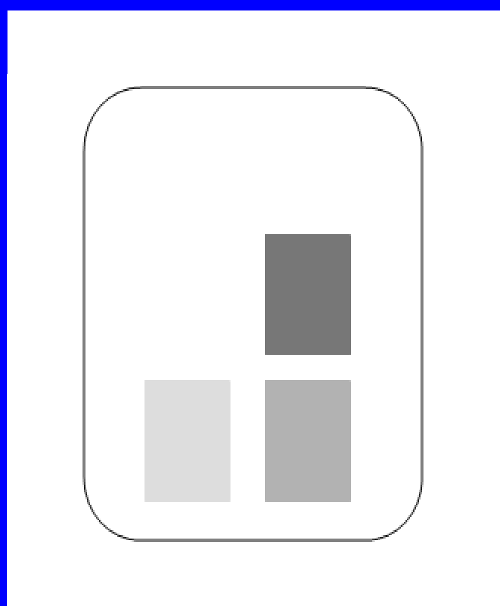
Exposure from front, square image



Exposure from back, round image

Acute vs Prolonged Exposure

If the exposure occurred for a very short time, the image of the filters on the developed film should have sharp well defined edges. If the exposure was prolonged, the images should be less distinct.

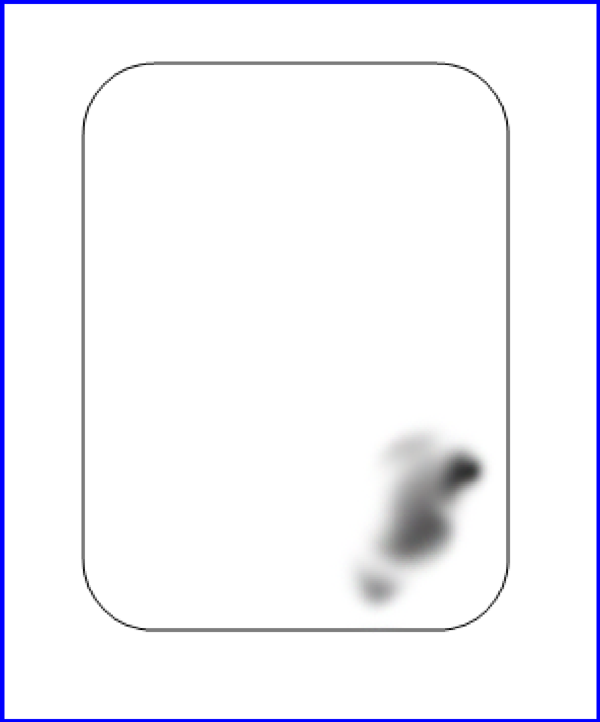


Acute Exposure

Prolonged Exposure

Contaminated Badge

An irregular unusual image might indicate the the badge (or the film) had become contaminated.



Contaminated
Badge/Film

Advantages and Disadvantages of Film Dosimetry

Advantages of Film Dosimetry

- The dosimeter itself serves as a permanent record
- The film can be reread
- Film is available in a wide range of sizes
- The photographic image can indicate the presence of contamination on the badge
- The photographic image can distinguish acute short term exposures from chronic exposures.

Disadvantages of Film Dosimetry

- The response of film is very dependent on the energy of the photons.
- Accurate estimations of the dose require careful and consistent processing of the film.