- HW2 AVAILABLE TODAY
- HW3 AVAILABLE BY FRIDAY
- HW4 POSTED ON WEB
- ADDITIONAL ADVANCED LECTURE AND HOMEWORK/LAB EXERCISES STARTING NEXT WEEK (OPTIONAL!)
- MIDTERM 10/20 - 10/23 IN TESTING CENTER
- I WILL PROVIDE A REVIEW SHEET BY FRIDAY 10/16

MONTE CARLO FOR HOMEWORK!

LAST TIME:

PHOTON FLUENCE & FLUENCE RATE:

$$\Phi = \frac{N}{A} \quad \begin{array}{l} \leftarrow \text{\# PHOTONS} \\ \leftarrow \text{AREA} \end{array}$$

$$\phi = \frac{N}{A \Delta t}$$

ENERGY FLUENCE & FLUENCE RATE:

$$\Psi = \frac{N h\nu}{A}$$

$$\psi = \frac{N h\nu}{A \Delta t}$$

ALSO KNOWN AS "INTENSITY"

$$I = E\phi = h\nu\phi$$

MONOENERGETIC SOURCES

INTENSITY: ENERGY PER UNIT AREA PER UNIT TIME.

POLYENERGETIC SOURCES:

- N AS A FUNCTION OF E YIELDS "LINE SPECTRUM".
- x-ray SPECTRUM $S(E)$ ⟸ # PHOTONS PER UNIT ENERGY PER UNIT TIME.

$$\phi = \int_0^\infty S(E')\,dE'$$

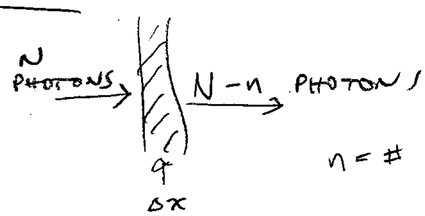
$$I = \int_0^\infty E' S(E')\,dE'$$

⟸ INTENSITY OF POLYENERGETIC SOURCE

LINEAR ATTENUATION COEFFICIENT:

$$\mu = \frac{n/N}{\Delta x}$$

⇑ LINEAR ATTENUATION COEFFICIENT



n = # PHOTONS LOST

WHAT IS THE CHANGE IN # OF PHOTONS THAT INTERACT W/ SLAB?

(AFTER SLAB: $N-n$; BEFORE SLAB: N)

$$\Delta N = (N-n) - N = -n = -\mu \Delta x N$$

$$\frac{\Delta N}{N} = -\mu \Delta x$$

NOW LET $\Delta x \to 0$:

$$\frac{dN}{N} = -\mu dx \xrightarrow{\text{INTEGRATING}} \boxed{N = N_0 e^{-\mu \Delta x}}$$

FUNDAMENTAL PHOTON ATTENUATION LAW.

CAN ALSO WRITE IN TERMS OF INTENSITY:

$$\boxed{I = I_0 e^{-\mu \Delta x}}$$

WHAT THICKNESS OF MATERIAL WILL ATTENUATE 50% OF THE PHOTONS?

$$\frac{N}{N_0} = \frac{1}{2} = e^{-\mu \Delta x}$$

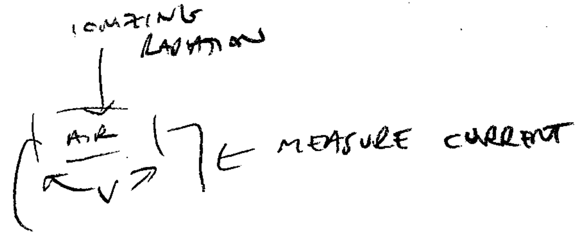
$$e^{\mu \Delta x} = 2$$

$$\mu \Delta x = \ln 2$$

$$\boxed{\Delta x = \frac{\ln 2}{\mu}}$$

RADIATION DOSIMETRY:

- IONIZATION CHAMBER:



- INVERSE SQUARE LAW FOR POINT SOURCE
- EXPOSURE: $\frac{\text{COULOMBS}}{\text{Kg}}$ OF AIR OR ROENTGEN (R) $\left(2.58 \times 10^{-4} \frac{C}{Kg}\right)$
- DOSE: ABSORPTION OF $100 \frac{\text{ergs}}{\text{gram}}$ OF MATERIAL = 1 rad.

| 1 ROENTGEN ≈ 1 rad IN SOFT TISSUE |

PROJECTION RADIOGRAPHY:

ADVANTAGES:

- SHORT EXPOSURE TIME (100 mS)
- LARGE FOV
- LOW COST
- LOW RADIATION EXPOSURE (30 mR) ⇐ 300 mR IS BACKGROUND ANNUAL DOSE
  - FLUOROSCOPY ⇒ SEVERAL REMS
- EXCELLENT CONTRAST & SPATIAL RESOLUTION.

DISADVANTAGES:

- 2D PROJECTION
- RADIOGENIC CARCINOGENESIS

USED FOR:

- CHEST (PNEUMONIA)
- HEART DISEASE
- LUNG DISEASE
- BONE FRACTURES
- CANCER (MAMMOGRAPHY)
- VASCULAR DISEASE

- X-RAY TUBES
- FILTRATION / RESTRICTION (↑ COLLIMATOR)
- COMPENSATION FILTERS
- CONTRAST AGENTS
- GRIDS,
- AIRGAPS
- SCANNING SLITS
- INTENSIFYING SCREENS
- RADIOGRAPHIC FILM
- CASSETTE
- X-RAY IMAGE INTENSIFIERS
  - FLUOROSCOPY (LOW DOSE, REAL TIME)
- FILM-SCREEN EFFECTS
- FILM GRAIN

PRODUCING X-RAYS:

X-ray TUBE: SHOW DIAGRAM — (3-5 A, 6-12 VOLTS)

- CATHODE CURRENT HEATS FILAMENT, EMITS ELECTRONS (THERMAL EXCITATION, THERMIONIC EMMISSION)
- ACCELERATED TO ANODE BY A HIGH VOLTAGE (THE TUBE VOLTAGE) 30-150 kV
- ANODE IS TYPICALLY RHENIUM-ALLOYED TUNGSTEN COATED, ANODE MADE OF MOLYBDENUM. (FOR MAMMOGRAPHY, TARGET AREA IS ALSO MOLYBDENUM)
- BREMSSTRAHLUNG DOMINATES
- ONLY ~1% OF INCIDENT ELECTRON ENERGY IS CONVERTED TO X-RAYS. THE REST IS HEAT!
- ANODE SPINS.

TRANSFORM UP AC LINE VOLTAGE, THEN RECTIFY. GET SOME RIPPLE.

IMPORTANT PARAMETERS OF AN X-RAY TUBE:

⇒ N (# OF EMITTED PHOTONS) CONTROLLED BY THE CATHODE CURRENT × TIME THE CURRENT IS ON (mA-s).
TYPICAL VALUES: 6-100 mAs

⇒ ENERGY OF EMITTED PHOTONS (keV) CONTROLLED BY VOLTAGE BETWEEN CATHODE & ANODE (TUBE VOLTAGE)
TYPICAL VALUES ARE 50-125 kV.

FILTRATION:

- WE DON'T WANT LOW-ENERGY X-RAYS IN THE BODY!
  - ALMOST ENTIRELY ABSORBED!
  - CONTRIBUTE TO DOSE, BUT NOT IMAGE QUALITY!

  } BAD!
- FILTER OUT LOWER-ENERGY PHOTONS
  - ANODE ITSELF ABSORBS A LARGE FRACTION
  - GLASS HOUSING & FILM ON INSIDE
  - ADDED FILTERING ⇒ USUALLY ALUMINUM

    (MATERIALS RATED AS "mm OF Aluminum EQUIVALENT")
- CALLED "BEAM HARDENING"

COLLIMATORS

- LEAD W/ HOLES CUT IN IT
- NOT TERRIBLY COMPLICATED. :)
- SOME ARE ADJUSTABLE

COMPENSATION FILTERS:

- THICK PARTS OF THE BODY ATTENUATE MORE
- LEADS TO LARGE DYNAMIC RANGE ⇒ OVEREXPOSURE & UNDER EXPOSURE
- COMPENSATION FILTERS USED SO X-RAY DETECTOR REQUIRES A SMALLER DYNAMIC RANGE

CONTRAST AGENTS:

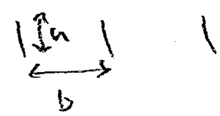
- HIGH Z
- IODINE (Z=53)
- BARIUM (Z=56)

} BLOCK X-RAYS WELL ABOVE CERTAIN FREQUENCIES ("K-EDGE ABSORPTION")

SHOW FIGURE 4.15
4.10
} ⇐ IN "FUNDAMENTALS OF MEDICAL IMAGING", PAUL SUETENS

SCATTER:

GRID RATIO = $\frac{h}{b}$



- AIRGAPS
- GRIDS ←
- SCANNING SLITS ←
  - SLIDE ALONG.
  - CAN PROVIDE 95% SCATTER REDUCTION
  - MORE COMPLEX, SLOWER, COST.

DETECTORS:

INTENSIFYING SCREENS:

- FILM ONLY STOPS 1-2% OF X-RAYS => INEFFICIENT AND HIGH DOSES!
  - ↑ % CONTRIBUTING PHOTONS = "QUANTUM EFFICIENCY" OF DETECTOR.
- FILM IS PLACED BETWEEN TWO "INTENSIFYING SCREENS"
- CONTAIN A "PHOSPHOR" W/ HIGH Q.E. => ABSORBS MOST X-RAY PHOTONS AND CONVERTS TO VISIBLE LIGHT.
- LIGHT IS SCATTERED IN ALL DIRECTIONS.
- OVERALL QE OF ~25% INSTEAD OF 1-2%

FLUORESCENCE: IMMEDIATE LIGHT EMISSION W/IRRADIATION, STOPS IMMEDIATELY AFTER.

PHOSPHORESCENCE: AFTER-GLOW => LIGHT PRODUCTION LASTS AFTER IRRADIATION, OR TAKES LONGER THAN 10^{-8} S TO REACH PEAK EMISSION.

- THOMAS EDISON => $CaWO_4$ (CALCIUM TUNGSTATE) GOOD FLOURESCENT PHOSPHOR FOR INTENSIFYING SCREENS.
- NOW RARE-EARTH PHOSPHORS ARE BETTER (LIKE Gd_2O_2S, GADOLINIUM OXYSULFIDE)

FILM:

- $AgBr$ => EMULSION W/ SILVER HALIDE CRYSTALS
- GRAINS ABSORB OPTICAL ENERGY, UNDERGO A COMPLEX PHYSICAL CHANGE.
- EACH GRAIN CONTAINS DARK, TINY PATCHES OF METALLIC SILVER => "DEVELOPMENT CENTERS"
- AMOUNT OF PHOTONS REQUIRED IS INDEPENDENT OF GRAIN SIZE!
- WHEN FILM IS DEVELOPED, THE DEVELOPMENT CENTERS PRECIPITATE THE CHANGE OF THE ENTIRE GRAIN TO METALLIC SILVER.
- MORE LIGHT => MORE GRAINS PER AREA, DARKER AREA ⇐ NEGATIVE FORMED
- AFTER DEVELOPMENT, FILM IS FIXED BY REMOVING REMAINING SILVER HALIDE CRYSTALS.

FILM => (CONT.)

- IN RADIOGRAPHY, THE "NEGATIVE" IS FINAL IMAGE
- CHARACTERISTICS OF FILM:

GRAININESS:

- FASTER FILMS ARE MORE GRAINY, SINCE AMOUNT OF PHOTONS NEEDED TO CHANGE A GRAIN TO METALLIC SILVER UPON DEVELOPMENT IS INDEPENDENT OF GRAIN SIZE

CONTRAST:

- "SENSITOMETRIC CURVE" SHOW FIGURE 4.4 IN "FUNDAMENTALS OF MEDICAL IMAGING", PAUL SUETENS

SPEED:

- INVERSELY PROPORTIONAL TO # OF PHOTONS NEEDED TO PRODUCE A GIVEN AMOUNT OF METALLIC SILVER ON DEVELOPMENT.

RESOLUTION:

- DEPENDS ON GRAIN SIZE AND LIGHT-SCATTERING PROPERTIES OF THE EMULSION AND PHOSPHOR INTENSIFYING SCREEN

IMAGE INTENSIFIERS:

- USUALLY FOR FLUOROSCOPY (LOW DOSE, REAL TIME)
- SHOW FIGURE 4.5 IN "FUNDAMENTALS OF MEDICAL IMAGING", PAUL SUETENS

- GENERALLY WORSE SPATIAL RESOLUTION THAN FILM (LIMITED CAMERA RESOLUTION)
- INCREASED NOISE (CONVERT PHOTON → ELECTRON → VISIBLE PHOTON)
- GEOMETRIC DISTORTION.

IN "FUNDAMENTALS OF MEDICAL IMAGING", SUETENS

STORAGE PHOSPHORS

(SHOW FIGURE 4.6)

- "COMPUTED RADIOGRAPHY"
- USE A SCREEN COATED WITH A "STORAGE PHOSPHOR"
  - → EXCITE ELECTRONS
  - → TRAPPED BY "ELECTRON TRAPS" (IMPURITIES IN THE PHOSPHOR")
  - → TAKES 8 HOURS TO DECREASE STORED ENERGY BY ABOUT 25%!
  - → PIXELWISE SCANNING WITH A LASER RELEASES PHOTONS (AS VISIBLE LIGHT)
  - → ERASE BY EXPOSING TO BRIGHT LIGHT SOURCE.

"PHOTO-STIMULATED LUMINESCENCE"

DIRECT RADIOGRAPHY:

- FLAT-PANEL DETECTORS
- VERY FAST!
- USUALLY SMALL (BAD) LIKE CCD'S (BASED ON SILICON CRYSTAL TECHNOLOGY)
- RECENT GOOD SCINTILLATOR ⇒ THALLIUM-DOPED CESIUM IODIDE.