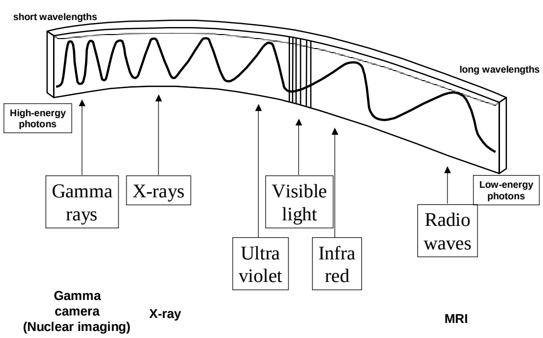
Image Sciences Institute

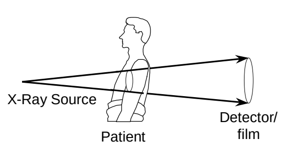
X-ray imaging techniques:
How x-ray images are created

Literature: Farr & Allisy-Roberts, chapter 2 & 3

Electromagnetic spectrum



Terminology



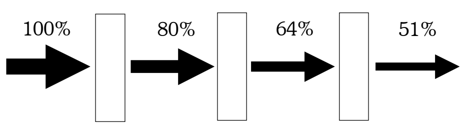
- Transmission
  - Photons passing through the body
- Absorption
  - Partial or total absorption of energy in the patient
- Scatter
  - Radiation diverted in a new direction

Attenuation processes

- Compton interaction
- Photo-electric absorption
- Interaction with bound electron

Fundamental law of attenuation

- Equal thicknesses of absorber transmit equal fractions (percentages)
- Example: material with transmission of 80%:



Conventional X-ray imaging

- The x-ray beam leaving the patient carries absorption pattern dependent on the thickness and composition of the body
- Scattered photons are superimposed
- Image captured on phosphor screen: conversion to visible light
- Imaging in 2 ways:
  - Recording on film (negative image)
  - Display on video monitor (positive image)

Patient dose

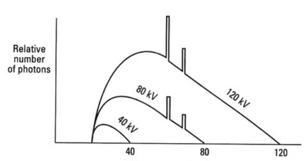
- Energy per unit mass
- Expressed in Gray's: 1 Gy=1 J/kg

Patient dose

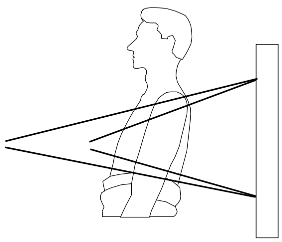
- Minimum dose required for satisfactory image:
  - 1μGy per radiograph
  - 1μGy or less per second in fluoroscopy
- This is the exit dose
- Entry dose
  - 10 times higher for anteroposterior chest
  - 100 times for anteroposterior abdomen or skull
  - 1000! times for a lateral pelvis

Limiting patient dose

- Increasing kV
  - Beam more penetrating -> higher percentage of high energy photons that reach the film-screen
  - Lower entrance dose required
  - Skin dose ≈ kV^2 ; Film-screen dose ≈ kV^4



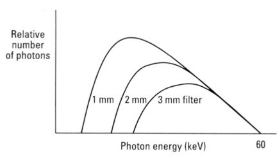
Limiting patient dose



- Increasing focus-film distance: increases body surface exposed and thereby lowers the skin dose
- Charge (mAs) has to increase to compensate for longer distance

Limiting patient dose

- Filtration (previous class)
  - Remove low energy photons which will not reach the film, prior to entering the patient

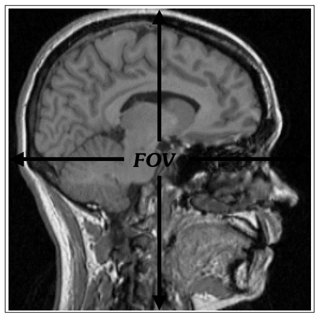


Subject contrast

- Structures in patient visible by
  - Resolution, sharpness, or lack of blurring
  - Contrast between adjacent objects

Spatial resolution

- Pixel size and amount of blurring determine sharpness of the image
- (NOTE: example image is MRI image!)

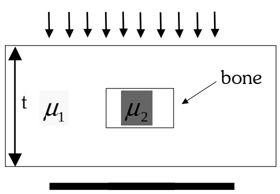


Contrast

$$I(x) = I_0 \cdot e^{-\mu x}$$

$$C \propto (\mu_1 - \mu_2) \cdot t$$

- Determined by
  - Thickness of structures
  - Difference in linear attenuation coefficients μ_1 and μ_2

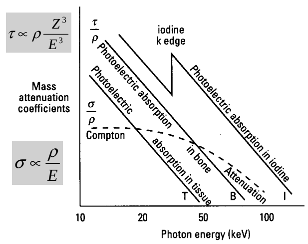


Contrast in X-Ray imaging

- Large contrast between bone and muscle
  - Decreases with increasing kV (photoelectric absorption in bone much larger at low energies)
- Little contrast between muscle and soft tissue
- Large difference between air and tissue (owing to difference in density)

Contrast in X-Ray imaging

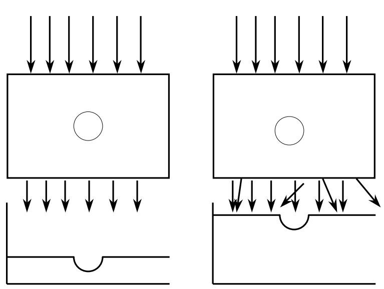
- Due to different attenuations of materials
- Shortcoming: little contrast between various soft tissues
- Contrast media
  - K-edge (photoelectric absorption)
    - Barium
    - Iodine



Scattered radiation

- Diagnostic relevant information contained in primary (unscattered) radiation (P)
- Scattered radiation (S) may be several times higher (typically 4) and acts like a veil over the image, reducing the contrast

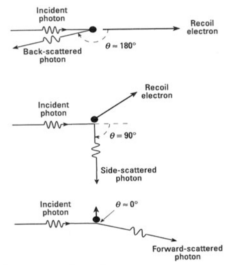
Primary and scatter image



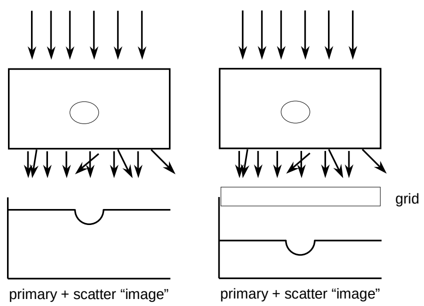
primary “image” primary + scatter “image”

Scatter reduction and contrast improvement

- Reduce scatter produced by patient
  - Reducing field size
    - Reducing field of view, e.g. using a diaphragm, reduces the volume of scattering tissue
  - Compression of the patient
    - Also reduces volume of scattering tissue
  - Using lower kV
    - Less forward scatter, and more side scatter



Scatter reduction and contrast improvement



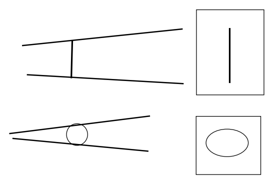
Scatter reduction after beam has left the patient

- Air gap
  - Slightly decreases primary radiation
  - Strongly decreases secondary radiation

  - Requires higher kV and-or mA
  - Results in a magnified image

Magnification and distortion

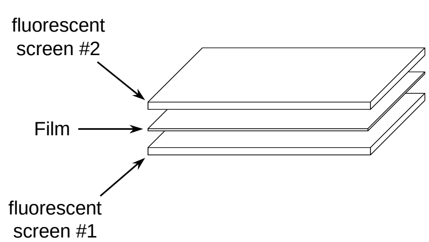
- X-ray images are projection images



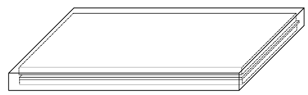
X-Ray imaging with films and screens

- Film can be exposed directly (highest resolution)
- Intensifying screen can be placed in front of the film
  - Increased contrast
  - Reduced sharpness

Film with intensifying (fluorescent) screens



Screen-film cassette

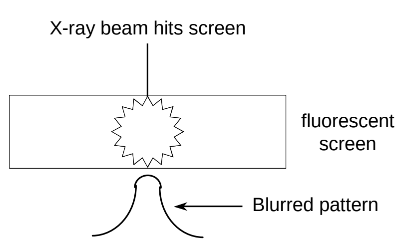


Assembled screen-film “sandwich” in light-tight cassette

Properties of film/screen assembly

- Intensifying screens absorb X-Rays and transfer into visible light.
- Film detects lights which is emitted by the screens
- Cassette is light-tight
- After exposure, film can be viewed as a semi-transparant on a light screen

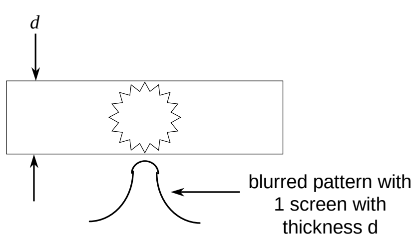
X-ray absorption in fluorescent screens



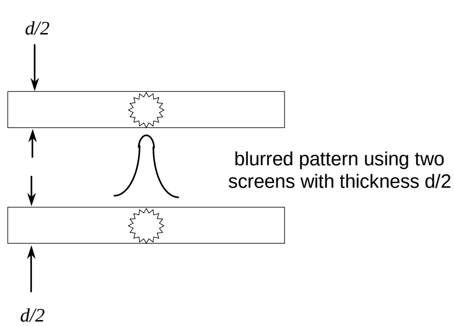
Scattered radiation

- Made of materials with high atomic number Z
- More efficient than film for stopping x-ray photons
- Thickness determines amount of absorption
- Thickness also determines amount of blurring

Two screens better than one

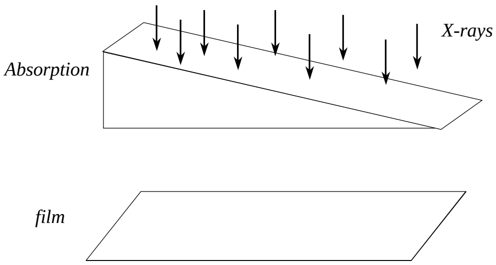


Two screens better than one



Medical Image Formation

X-ray film



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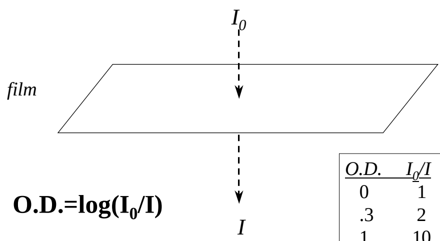
Medical Image Formation

Optical density



O.D.=log(I_0/I)

O.D.	*I_0/I*
0	1
.3	2
1	10
2	100
3	1000

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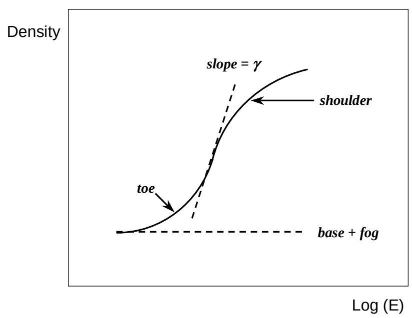
Medical Image Formation

Screen-film characteristic curve



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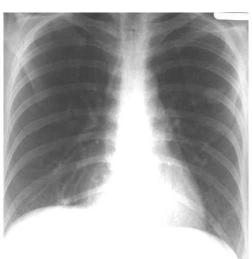
Film properties

- Characteristic curve determines response of screen/film combination to x-rays
- Maximal slope γ determines maximal contrast
- Middle part of slope is linear and most suited for imaging
- Contrast is bad at “toe” and “shoulder”

Current applications

- Plain radiography
- Mammography
- DSA = Digital Subtraction Angiography
- CT = Computer Tomography
- CTA = CT Angiography
- RX(A) = Rotational X-ray (Angiography)

Plain radiography



Thorax (TBC)

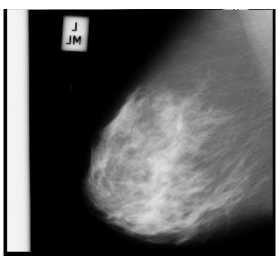
Fractures

Pros and cons

- Fast
- Not expensive

- Ionising radiation involved
- Projection images
- Low blood vessel and soft-tissue contrasts

Mammography



Visualizing microcalcifications (0.1 mm) with high contrast

Mammography

- Low kV can be used (little attenuation)
- This results in sufficient photoelectric absorption to differentiate between normal tissue and pathology
- Dose needs to be limited
- Breast must be compressed
  - To avoid motion
  - To minimize focus/film distance
  - To have equal tissue thickness

Fluoroscopy

- Real-time x-ray imaging
- Directly onto screen
- Used for guidance of interventions (mainly vascular and orthopedic)
- Gamma=1: intensity linear in exposure
- Uses image intensifier

Image intensifier

- Fluorescent screen converts x-rays to visible light
- Photons release electrons at kathode of the image intensifier
- Elektrons are accelerated and focussed
- Brightness is considerably increased (factor 1000)

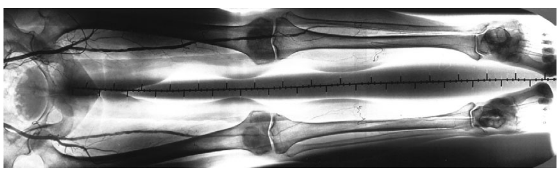
DSA = Digital subtraction angiography (using contrast agent)

For interventions like:

PTA (Dotter) procedures

Aneurysma embolisation

Angiographic “bolus chase” reconstruction



Reconstructed from a series of exposures from the acquisition system tracking a ***single*** bolus of contrast medium through the lower extremities.

Philips EasyVision RF workstation

Pros and cons

- Gold standard in vascular diagnostics
- High resolution

- Invasive procedure (catheter)
- Projection
- Contrast agent needed
- Ionising radiation