- SHIFT IN SYLLABUS
- HW 3 POSTED ON WEB
- HW HELP SESSION THIS EVENING AT 5PM (LOCATION?)
- LECTURES THROUGH LECTURE 7 POSTED ON WEB (USE AT YOUR OWN RISK!)
- HW 2 SOLUTIONS POSTED ON WEB

ARTIFACTS: IMAGE FEATURES THAT DO NOT REPRESENT VALID ANATOMICAL OR FUNCTIONAL CHARACTERISTICS OF THE OBJECT BEING IMAGED.

DISTORTION: GEOMETRIC DISTORTION → INABILITY OF A MEDICAL IMAGING SYSTEM TO GIVE AN ACCURATE IMPRESSION OF THE SHAPE, SIZE, AND/OR POSITION OF OBJECTS OF INTEREST.

ACCURACY:

QUANTITATIVE ACCURACY: WE SOMETIMES ARE INTERESTED IN A NUMERICAL VALUE OF A GIVEN ANATOMIC OR FUNCTIONAL FEATURE WITHIN AN IMAGE.

- TUMOR DIMENSIONS FROM RADIOGRAPH
- GLUCOSE METABOLIC RATE FROM NUCLEAR MEDICINE IMAGE

WE NEED TO KNOW ERROR.

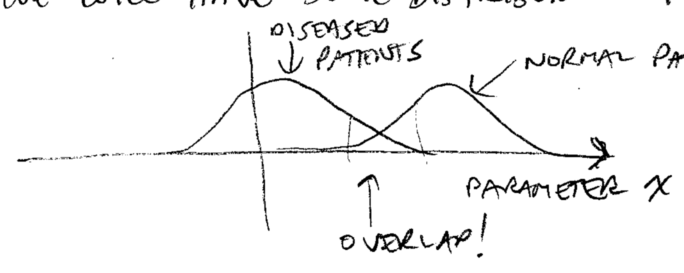
TWO SOURCES:

- SYSTEMATIC ERROR OR BIAS ⇐ CAN CORRECT FOR
  ↑ REPRODUCIBLE

- IMPRECISION OR STATISTICAL ERROR ⇐ RANDOM MEASUREMENT-TO-MEASUREMENT VARIATION

DIAGNOSTIC ACCURACY:

SUPPOSE WE MEASURE SOME PARAMETER (OR SET OF PARAMETERS) OF INTEREST IN A PATIENT. IN NORMAL (UNDISEASED) PATIENTS WE WILL HAVE SOME DISTRIBUTION OF THE PARAMETER:



SAME IN DISEASED PATIENTS.

USUALLY SOME OVERLAP. WHERE SHOULD THE THRESHOLD BE?

TWO PARAMETERS ARE COMMONLY USED IN A CLINICAL SETTING:

<u>SENSITIVITY</u>: (OR <u>TRUE-POSITIVE FRACTION</u>)
FRACTION OF PATIENTS <u>WITH DISEASE</u> WHO TEST <u>POSITIVE</u>.

<u>SPECIFICITY</u>: (OR <u>TRUE-NEGATIVE FRACTION</u>)
FRACTION OF PATIENTS <u>WITHOUT DISEASE</u> WHO TEST <u>NEGATIVE</u>.

CAN USE A <u>CONTINGENCY TABLE</u>:

		DISEASE YES	DISEASE NO
TEST	+	a	b
	−	c	d

⇐ FOUR GROUPS:
- a AND d CLASSIFIED CORRECTLY
- b AND c INCORRECTLY CLASSIFIED

$$\text{SENSITIVITY} = \frac{a}{a+c}$$

$$\text{SPECIFICITY} = \frac{d}{b+d}$$

<u>DIAGNOSTIC ACCURACY</u> ⇐ FRACTION OF PATIENTS DIAGNOSED CORRECTLY

$$DA = \frac{a+d}{a+b+c+d}$$

⇑ THIS ALONE ISN'T A GOOD MEASURE. CONSIDER A GROUP OF 100 PATIENTS (98 NORMAL AND 2 DISEASED). OUR "TEST" SIMPLY LABELS ALL PATIENTS NORMAL. WHAT IS DA.?

<u>CHOOSING THE THRESHOLD</u>:
- DEPENDS HEAVILY ON THE RELATIVE COST-OF-ERRORS IN CALLING A NORMAL PATIENT DISEASED OR VICE VERSA!

<u>TO OTHER PARAMETERS</u>:

<u>POSITIVE PREDICTIVE VALUE (PPV)</u>: $PPV = \frac{a}{a+b}$
FRACTION OF PATIENTS WHO TEST POSITIVE THAT ACTUALLY HAVE THE DISEASE.

<u>NEGATIVE PREDICTIVE VALUE (NPV)</u>: $NPV = \frac{d}{c+d}$
FRACTION OF PATIENTS WHO TEST NEGATIVE THAT REALLY DON'T HAVE THE DISEASE.

<u>PREVALENCE</u>: $PR = \frac{a+c}{a+b+c+d}$

RADIOGRAPHIC IMAGING — CHAPTERS 4, 5, AND 6

IONIZING RADIATION: RADIATION CAPABLE OF EJECTING ELECTRONS FROM ATOMS.

- BASIS FOR PROJECTION RADIOGRAPHY AND CT (TRANSMISSION OF IONIZING RADIATION THROUGH BODY).
- BASIS FOR NUCLEAR MEDICINE (EMISSION OF IONIZING RADIATION FROM BODY).

PROJECTION RADIOGRAPHY AND CT:

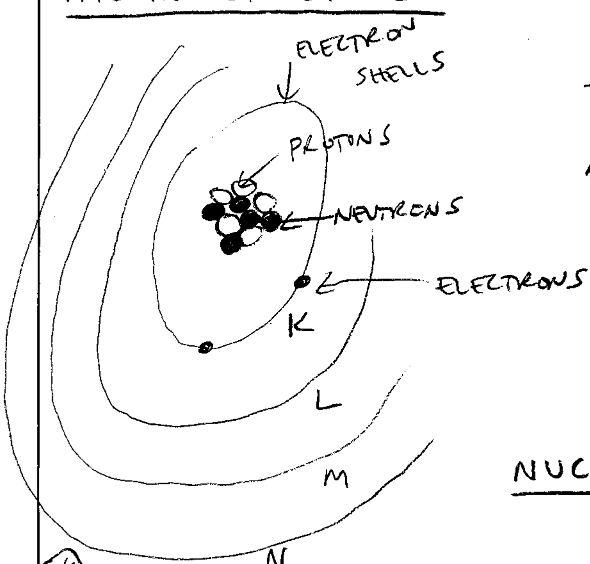
- TRANSMISSION
- VARIOUS TISSUES AND ORGANS ATTENUATE OR DECREASE INTENSITY OF THE BEAM, BASED ON DENSITY AND EFFECTIVE ATOMIC NUMBER.
- "ANATOMICAL" (AND NOT "FUNCTIONAL") IMAGING MODALITIES!

PHYSICS OF RADIOGRAPHY

RADIOGRAPHY ⇒ NO RADIOACTIVITY! (THAT'S NUCLEAR MEDICINE)

X-RAYS DISCOVERED IN 1895 BY ROENTGEN WORKING WITH A CROOKE'S TUBE.

ATOMIC STRUCTURE



$2n^2$ ELECTRONS ALLOWED IN n^{th} SHELL!

Z = ATOMIC # (# OF PROTONS)

A = MASS # (# OF NUCLEONS)

A → ^{14}C ← TELLS US Z

^{23}Na

NUCLIDE ⇒ ANY UNIQUE COMBINATION OF PROTONS & NEUTRONS THAT FORMS A NUCLEUS

SOME NUCLIDES UNSTABLE!

$^{14}_{6}C \longrightarrow {}^{14}_{7}C$ + BETA PARTICLE "RADIOACTIVITY"

IONIZATION:

- THE EJECTION OF AN ELECTRON FROM AN ATOM, CREATING A FREE ELECTRON AND AN ION.

RADIATION THAT CARRIES ENOUGH ENERGY TO IONIZE AN ATOM IS CALLED "IONIZING RADIATION".

- x-rays, gamma rays ARE IONIZING
- LIGHT AND RADIO WAVES ARE NOT (TOO LOW ENERGY)
- ELECTRON BEAMS? SOMETIMES (DEPENDING ON ENERGY OF EACH PARTICLE)

"BINDING ENERGY" OF ELECTRON:

1 eV ⇒ KINETIC ENERGY GAINED BY AN ELECTRON WHEN ACCELERATED ACROSS 1 VOLT POTENTIAL

- HOW MUCH ENERGY IT TAKES TO POP OFF AN ELECTRON FROM AN ATOM (TO IONIZE IT)
- FOR HYDROGEN ⇒ 13.6 eV
  - SMALLEST BINDING ENERGY FOR LIGHTER ATOMS
  - OUTER ORBITS OF HEAVIER ELEMENTS CAN HAVE LOWER (O-SHELL OF Hg IS ABOUT 7.8 eV)
- BINDING ENERGIES GET SMALLER AS YOU MOVE TO INCREASING SHELL NUMBERS.
- METALS HAVE SIGNIFICANTLY LARGER AVERAGE ELECTRON BINDING ENERGIES.
  - LEAD IS ABOUT 1 keV
  - TUNGSTEN IS ABOUT 4 keV ⇐ IMPORTANT LATER

ENERGY GREATER THAN 13.6 eV IS CONSIDERED IONIZING (BY CONVENTION)

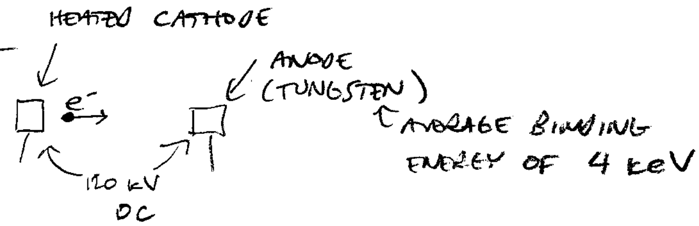
IONIZATION: KNOCK AN ELECTRON OUT, LEAVING A "HOLE"

EXCITATION: KNOCK AN ELECTRON TO A HIGHER ENERGY STATE, LEAVING A "HOLE".

IN MEDICAL IMAGING, OUR IONIZING RADIATION HAS ENERGIES RANGING FROM ABOUT 25 keV TO 500 keV.

↑ CAN IONIZE MAYBE 10 TO 40,000 ATOMS ON AVERAGE

EXAMPLE:

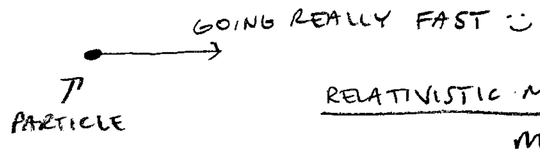


QUESTION:
HOW MANY TUNGSTEN ATOMS COULD THE ELECTRON IONIZE AT THE ANODE?

ANSWER: 30

FORMS OF IONIZING RADIATION:

(1) **PARTICULATE:** (PROTONS, ELECTRONS, NEUTRONS)



RELATIVISTIC MASS:

$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$ ← REST MASS

FROM EINSTEIN:

$$E = mc^2$$ ⟸ TOTAL ENERGY OF A PARTICLE

SO WHAT IS THE KINETIC ENERGY OF A RELATIVISTIC PARTICLE?

$$KE = E - E_0 = mc^2 - m_o c^2$$

$$KE = \frac{m_o c^2}{\sqrt{1 - \frac{v^2}{c^2}}} - m_o c^2$$

$$\boxed{KE = m_o c^2 \left(\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right)}$$

$$\left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}} \qquad (1 - \varepsilon)^x \approx 1 - \varepsilon x$$

SO: $\left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}} \approx 1 + \frac{1}{2}\frac{v^2}{c^2}$ FOR $\frac{v^2}{c^2} \ll 1$

$$KE \approx m_o c^2 \left(\cancel{1} + \frac{1}{2}\frac{v^2}{c^2} - \cancel{1} \right) \approx \frac{1}{2} m_o v^2$$

IN PROJECTION RADIOGRAPHY (x-ray) AND CT, WE'RE ONLY WORRIED ABOUT ELECTRON PARTICULATE RADIATION.

EXAMPLE: IS RELATIVITY IMPORTANT IN OUR PREVIOUS EXAMPLE?

$m_e = 9.11 \times 10^{-31}$ kg.

KE = 120 keV

SO, FOR NON-RELATIVISTIC SPEEDS, WE HAVE:

$KE = \frac{1}{2} m_e v^2 = 120\,keV$

SOLVING FOR v:

$v = 2.054 \times 10^8$ m/s ⇐ IS THIS A RELATIVISTIC SPEED? YES! :)

(2) ELECTROMAGNETIC RADIATION: WE SHOULD ALL KNOW WHAT THIS IS. (RADIO WAVES, MICROWAVES, INFRARED LIGHT, VISIBLE LIGHT, ULTRAVIOLET LIGHT, X-RAYS, GAMMA RAYS)

- CAN VIEW AS PACKETS OF ENERGY, OR "PHOTONS"
- HAS NO REST MASS AND NO CHARGE!

WHAT IS THE ENERGY OF A PHOTON OF FREQUENCY ν?

$$E = h\nu$$

ν ⇐ FREQUENCY

h ⇑ PLANCK'S CONSTANT (6.626×10^{-34} JOULE · sec)

$$\lambda = \frac{c}{\nu}$$

λ ⇑ WAVELENGTH

	FREQUENCY	WAVELENGTH	PHOTON ENERGY
RADIO WAVES:	100 kHz – 30 GHz	3 km – 1 cm	413 peV – 124 μeV
	⋮		12.4 meV – 1.24 eV
INFRARED:			
VISIBLE LIGHT:			
ULTRAVIOLET:			
X-rays:			
gamma rays:			

CHART ON P. 112

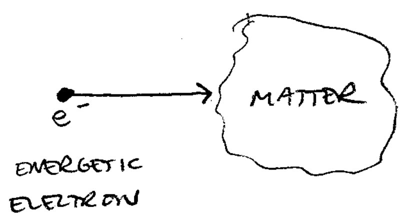
PARTICULATE AND EM RADIATION INTERACTIONS W/ MATERIALS

WHEN THESE TWO TYPES OF RADIATION INTERACT WITH MATERIALS, A NUMBER OF THINGS CAN HAPPEN:

- IMPART ENERGY TO THE MATERIAL
- LOSE THEIR OWN ENERGY
- REDIRECT THEIR OWN RADIATION
- GENERATE NEW TYPES OF PARTICLES AND RADIATION

PARTICULATE RADIATION INTERACTIONS:

WE'RE ONLY GOING TO WORRY ABOUT <u>ENERGETIC ELECTRONS</u> RIGHT NOW.



3 TYPES OF INTERACTION

① COLLISIONAL TRANSFER:

- ELECTRON GLANCES OFF ANOTHER ELECTRON, LOSING SOME ENERGY AND EXCITING IT. AS EXCITED e^- RETURNS TO GROUND STATE, IT EMITS INFRARED, HEATING THE OBJECT.
- SOMETIMES A COLLISION IS DIRECT ENOUGH TO IONIZE AN ELECTRON (FORMING A NEW ENERGETIC ELECTRON CALLED A "DELTA RAY")!

RADIATIVE TRANSFER:

② CHARACTERISTIC RADIATION:

- ELECTRON UNSEATS A K-shell ELECTRON
- THE "HOLE" IS FILLED BY AN L, M, OR N-SHELL ELECTRON.
- AN X-ray PHOTON IS RELEASED (DIFFERENCES IN BINDING ENERGY IS IN X-ray RANGE)
- ONLY HAPPENS AT DISCRETE ENERGIES (EXACT DIFFERENCE IN BINDING ENERGIES BETWEEN THE SHELLS)

TALK ABOUT FIGURE 4.5, p. 116

③ BREMSSTRAHLUNG RADIATION:

PRIMARY SOURCE OF X-rays IN AN X-ray TUBE

- "BRAKING" RADIATION
- NOT JUST AT DISCRETE ENERGIES!