Non Ionizing Radiation

- Nonionizing radiation - Energy < 12.4 eV

← ← ← ← ← ← ← ***Energy*** ← ← ← ← ← ←

Ultraviolet

Visible

Infrared

Microwave

Radiofrequency

Extremely low frequency

Radiation Physics (basics)

- Electromagnetic Radiation (EMR)
  - EMR is energy in motion: consider-
    - oscillating electric (E)
    - magnetic (H) fields
- Characteristics
    - Wavelength (λ)
      - Distance between two similar points on a wave
        - Units
          - meter (m), mm (10^{-3}m), µm (10^{-6}m), nm (10^{-9}m)

- Frequency (ν)
    - Number of wavelengths passing a given point per unit time
        - Units
            - Hertz (Hz)
                - kHz (10^3 Hz)
                - MHz (10^6 Hz)
                - GHz (10^9 Hz)
- Velocity (c)
    - Speed at which EMR travels (m/s)
        - 3×10^8 m/s
- Characteristics related by:
    - $c = 3 \times 10^8 \text{ m/s} = \lambda\nu$
- Calculate photon energy as follows
    - Q [electron volt (ev)] = $1.26/\lambda$ (μm)
    - 1 eV = 1.6x10-19 joule (J)

- EM spectrum-divided into regions
    - Optical
    - Radiofrequency (RF)
    - Extremely low frequency (ELF)

- EMR Interactions
    - Transmission
    - Absorption
    - Reflection (specular or diffuse)

- Optical Spectrum

Optical Region	**Wavelength Range**
Ultraviolet (UV)	100 - 400 nm
Vacuum UV	100 - 180 nm
UV-C	180 - 280 nm
UV-B	280 - 315 nm
UV-A	315 - 400 nm
Visible	400 - 760 nm
Infrared (IR)	760 nm - 1 mm
IR-A	760 - 1.4 μm
IR-B	1.4 - 3.0 μm
IR-C	3.0 μm - 1 mm

- Two systems of units are used
    - Radiometric terms
        - Describe physical properties of optical radiation in any region.
            - Source output
                - Energy (joule [J])

        - Power (watt [W])
            - 1 W = 1 J/second(s)
    - Exposure
        - Radiant exposure [H]
            - (J/cm^2)
        - Irradiance [E]
            - (W/cm^2)
- Photometric terms are used to describe visible radiation (light) only in terms of the human eye's response to the radiation
    - Source output is specified in terms of luminous flux
        - (lumens [lm])
    - Exposure
        - Illuminance (lm/m^2), or
        - Luminance (candela [cd] /cm^2)

- Optical Radiation Sources
    - Coherent sources
        - Emit a single wavelength in a tightly collimated beam

- Incoherent sources
    - Multiple wavelengths; one or more regions, multi-directional
        - Natural sources
            - Sun, flames, molten materials

        - Artificial
            - Lamps, arc processes, heaters, ovens, furnaces, flames, CRTs, diodes, luminescent materials
- Biological Effects
    - Critical organs
        - Skin
        - Eye
    - Effects on skin
        - UV exposure
            - Acute effect: erythema or reddening threshold depends on wavelength, prior exposure, pigmentation and exposure to photosensitizing agents
                - Photosensitizers reduce dose required to produce erythema
                    - Chemicals
                        - coal tar pitch, anthracene, naphthalene, thiophene, phenanthrene); plants
                        - figs, parsley, limes, parsnips)
                        - consumer products
                        - medications

        - Chronic exposure (sunlight): accelerates skin aging and increases the risk of skin cancers basal cell, squamous cell, melanoma
    - Visible and IR radiation
        - Thermal skin burns
            - Pain threshold lower than burn threshold
- Ocular Effects
    - Photokeratitis and conjunctivitis
        - Overexposure to UV-B and UV-C (200-315 nm)
            - Minimum threshold at 270 nm; latent period is 3-6 hr; with symptoms lasting up to 48 hr, usually with no residual damage
        - Cataracts
            - Acute exposure to UV-B and UV-C
                - (295-365 nm) in animal studies; in humans may be related to chronic sun exposure
                    - Glassworkers
                - IR-A (780-1400 nm) - human studies done in early 1900's (furnaceman's / glassmaker's cataract)

- Retinal scotoma or burn
    - Results from visible and near-IR
        - 380-1400 nm
            - exposure data from animal studies
            - photochemical mechanism in the blue light region
            - thermal mechanism at longer wavelengths
- Solar retinitis
    - eclipse blindness

- Control Measures
    - Source control
        - Source enclosure
        - Source operating time
    - Protective barriers and distance
        - Absorbing materials; reflections
    - Source/worker distance
    - Personal protective equipment
        - Protective eyewear - wavelength dependent; glass, some plastics absorb $\lambda < 320$ nm; special lenses and coatings absorb UV-A
        - Barrier creams/sunscreens - PABA, $Ti0_2$, salicylates, cinnamates and benzophenones

- Lasers and Laser Radiation
  - Types and applications
    - Material processing - high power IR lasers
    - Construction / surveying - low power HeNe
    - Medical / research - high power visible/IR
    - Other uses
      - Nondestructive testing, point-of-sale terminals, communications, art and light shows
  - Biological effects
    - Critical organs
      - Eye and skin
        - Effects - same as other optical sources
  - Hazard evaluation
    - Increased hazard due to
      - Invisible beams (cannot see IR radiation, cannot react to stimulus)
      - Hazardous specular and diffuse reflections
      - Highly concentrated beam (irrradiance)
      - Pulsed operation
  - Standards
    - ACGIH laser TLV
    - ANSI Z136-1986

        - OSHA (29CFR1926.54) - outmoded
        - FDA laser product standard (21CFR1040.10)
    - Hazard classification - based on its capability of injuring personnel
        - Requires the following information
            - Operating wavelengths
            - CW/repetitively pulsed lasers - average power and exposure duration
            - Pulsed lasers - energy/pulse or peak power, pulse length, pulses/second, and emergent beam radiant exposure
            - Classification scheme
                - FDA and ANSI are quite similar. FDA requires label

- Class I
    - Usually eye safe
- Class II
    - Visible lasers, safe for $t < 0.25$ s (blinking)
- Class IIa
    - Visible lasers, safe for $t < 1000$s (laser pointer)
- Class IIIa
    - Visible lasers; P = 1-5 mW
- Class IIIb
    - Viewing hazard from direct beam, specular reflection (dangerous)
- Class IV
    - Diffuse reflection viewing, skin, and fire hazard (starting around ½ Watt)

- Control measures - depend on the laser class
    - Class I - none required (unless embedded higher class laser)
    - Class II, IIa - caution label.
    - Class IIIa - caution label, beam stop
    - Class IIIb/IV - engineering/procedural controls; must determine areas above TLV:
        - Nominal hazard zone (NHZ) - area in which direct, reflected or scattered radiation levels during normal operation exceed TLV.
        - Nominal ocular hazard distance (NOHD) - distance along beam axis from laser to eye beyond which level does not exceed TLV.

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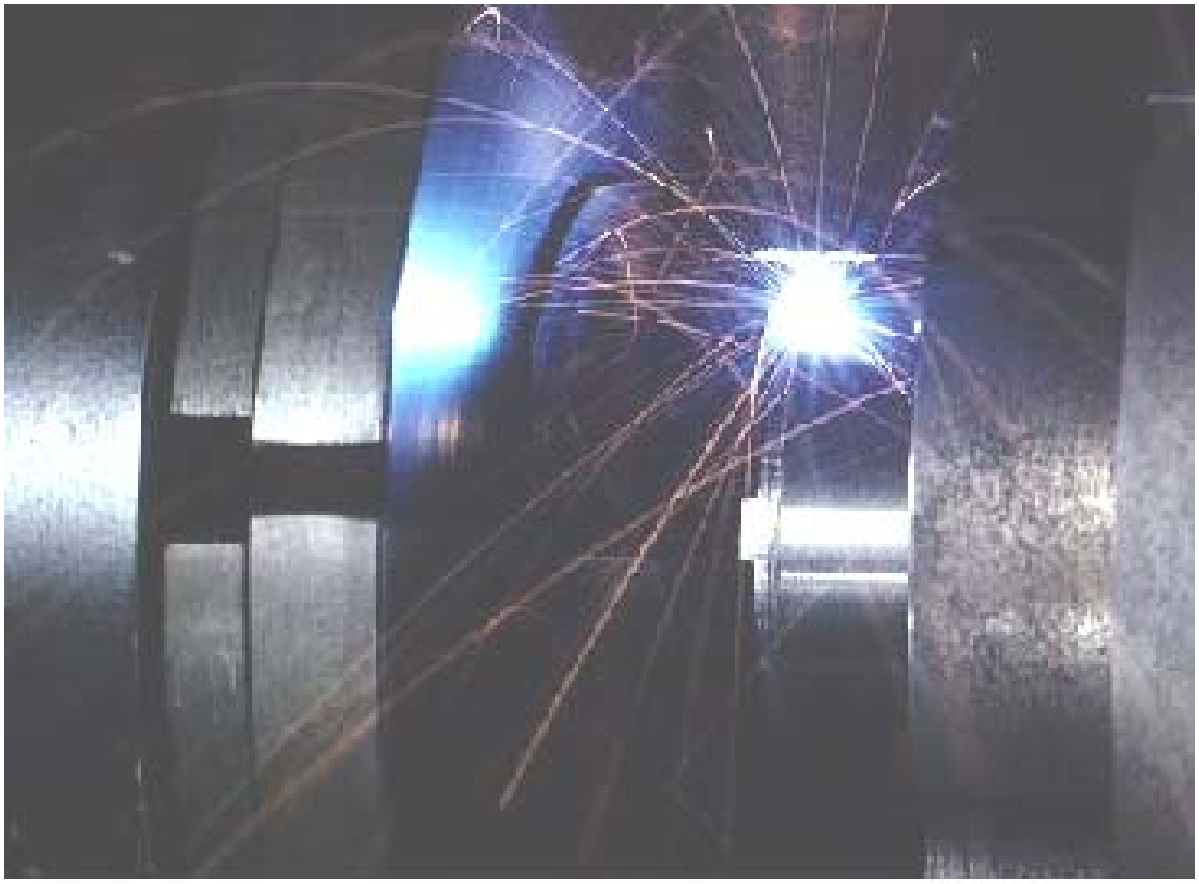

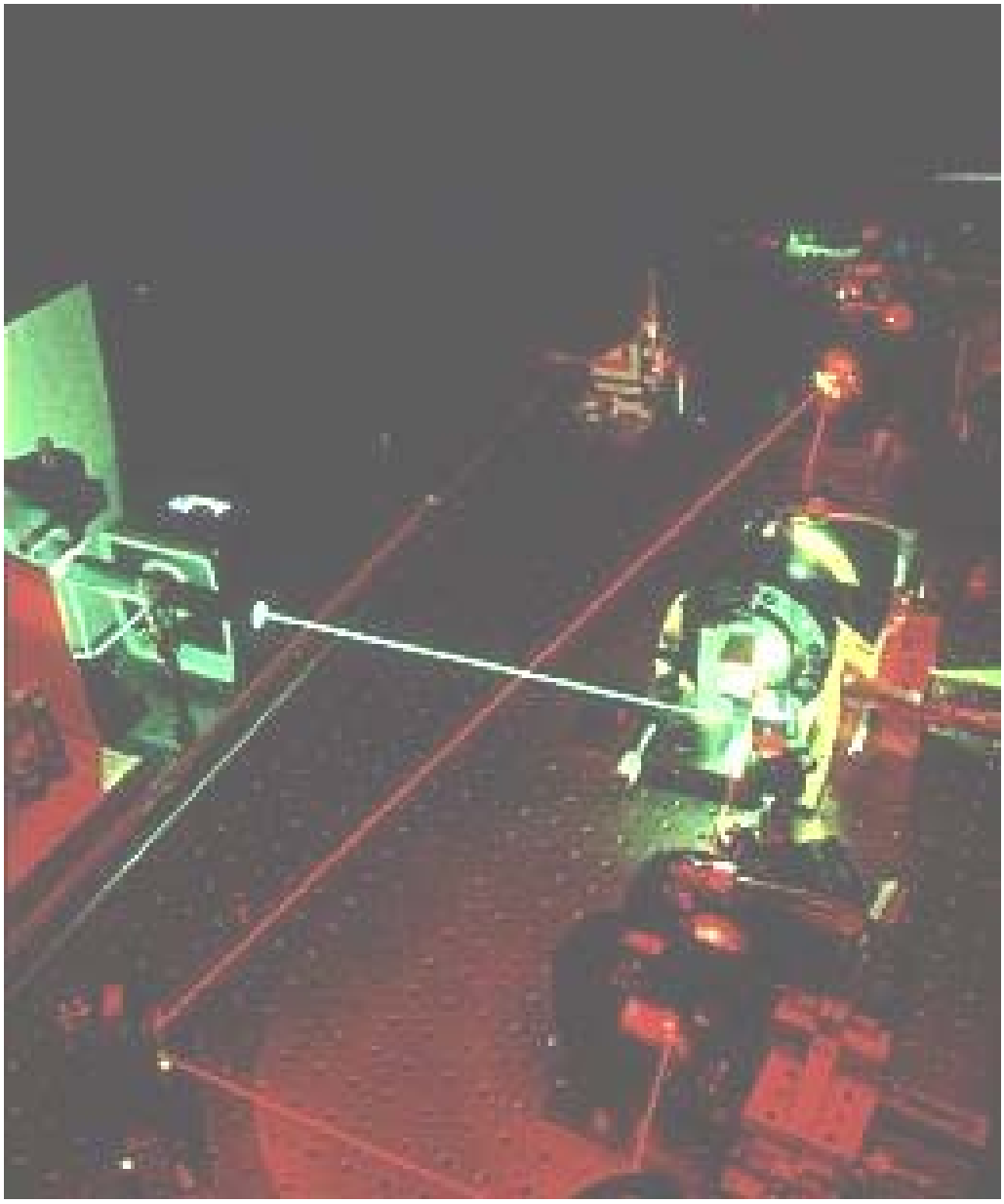

Radiofrequency / Microwave Radiation

- Introduction
  - Characteristics
    - Frequency (ν)
      - RF Region
        - 3 kHz to 300 MHz
      - MW Region
        - 300 MHz to 300 GHz
    - Wavelength (λ)
      - RF region - 100 km to 1 m
      - MW region - 1 m to 1 mm
  - EMR
    - electric (E)
    - magnetic (H) field
  - ➢ **Far field**
    - E and H are orthogonal (90° angle)
      - Inverse square law applies
    - Far field begins at:
      - Distance > 10 X the source wavelength
      - Distance > $2D^2/\lambda$
        - where D = largest dimension of the radiating antenna

- **Near field**
  - Distance < one wavelength
  - Angle between E and H is unknown, variable
  - Inverse square law does not apply!
- AM frequency ~ 300 m
- FM frequency ~ 75 m

- Exposure quantities and units
  - Power density (P) - valid only in far field!
    - Unit - mW/cm^2 or W/m^2
  - Field strength - used in the near field
    - Units
      - E-field strength
        - V^2/m^2 or V/m
      - H- field strength
        - $A^2/m2$ or A/m
    - Under 300 MHz, E and H must be measured separately in the workplace
  - Equivalent plane-wave power density
    - Convert E and H to power density:
      - P (mW/cm^2) = E^2 (V^2/m^2) /3770
      - P (mW/cm^2) = 37. 7 H^2 (A^2/m^2)
  - Specific Absorption Rate (SAR)
    - Rate of absorption of RF energy per unit mass
      - Unit - W/kg or mW/g

        - Cannot be measured in workplace
        - SAR varies greatly with frequency
        - Resonant absorption - 40-80 MHz
- Sources of Exposure
    - Most frequencies are used in communications and related applications.
    - Industrial, Scientific and Medical (ISM) bands
        - 6.78, 13.56, 27.12, 40.68, 915, 5800, 24,125, 61,250, 122,500, 245,000 (MHz)
        - Industrial sources - Dielectric and induction heating, arc welding, plasma etching, CRT/VDT units, microwave ovens
        - Medical sources - electrosurgical devices, diathermy, diapulse, epilators, tumor detection, hyperthermia cancer therapy and magnetic resonance imaging (MRI)
        - Scientific sources - plasma etchers, trace metal analyzers, lasers, induction heaters, CRT-based oscilloscopes and computer equipment
        - Consumer products - microwave ovens, intrusion alarms, CB radios, TVs, PCs

- Biological Effects
  - RF/MW absorption results in body heating if absorption exceeds dissipation by thermoregulatory system.
    - Most adverse effects accompanied by a temperature rise; some nonthermal changes
  - Incidence of effects correlates with SAR.
  - Human studies - case studies and epidemiologic studies have not been useful in determining effects on humans
  - Animal studies
    - Can raise core temperature several °C
    - Death from protracted exposures
  - Carcinogenicity - may be a promoter
  - Reproductive / Teratogenic
    - Impaired fertility, testicular damage, decreased sperm counts, malformations
  - Ocular effects - keratitis, lenticular opacities, cataracts at high exposures
  - Other effects/changes in endocrine, CNS, cardiovascular and hematologic systems, behavior, and immunologic function

- Hazard Evaluation
  - Exposure standards are based on animal studies
  - American National Standards Institute: Based on an SAR of 0.4 W/kg.
  - RF / MW PROTECTION GUIDES (ANSI C95.1-1992)
    - Part A - Electromagnetic Fields

Frequency Range (MHz)	E-Field (V/m)	H-Field (A/m)	PD (mW/cm^2)
0.003-0.1	614	163	NA
0.1-3.0	614	16.3/f	NA
3-30	1842/f	16.3/f	NA
30-100	61.4	16.3/f	NA
100-300	61.4	0.163	1.0
300-3000			f/300
3000-300,000			10

    - Part B – Induced and Contact RF Currents
      - Time-weighted-average (TWA) - weighted over 0.1-hr (6-min) for field strength only; 1 s for currents

Frequency (f) (MHz)	Maximum Current (mA) Both Feet	Each Foot	Contact (in any second)
0.003-0.1	2000 f	1000 f	1000 f
0.1-100	200	100	100

- Use duty factor (DF) or duty cycle (DC) to calculate TWA. DF / DC is unitless and has a value between 0-1
    - For intermittent sources, e.g., RF heaters, use the DF
        - DF = RF_{ON} (hr)/ 0.1 hr = RF_{ON} (s)/360 s
            - RF_{ON} = on time during a 0.1-hr period. For pulsed sources, e.g., radars, use the DC
        - DC = PW x PRF
            - PW = pulse width (s)
            - PRF = pulse repetition frequency (Hz)
        - Multiply measured value by DF or DC to obtain the TWA exposures.
        - Compare to exposure guideline.
- To evaluate hazard, need…
    - Frequency - From measurement or manufacturer's specifications
    - Time variation - continuous wave (CW), intermittent, pulsed, rotating
    - Use DF/DC as above.
- Exposure measurements
    - < 300 MHz, measure E- and H-field
    - > 300 MHz, measure power density

- Control Methods
  - Exposure duration - Time not applied as easily
  - Separation distance
    - Far field exposures
      - Inverse square law applies.
      - Many communication sources are directional; intensity drops quickly off the centerline of beam
    - Near field
      - Most exposures to ISM sources
      - Move operator station away from source; use conveyors.
  - Shielding
    - Most practical and effective control method to reduce exposure
    - Installed by manufacturer or retrofitted
    - Personal protective equipment - not used!

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