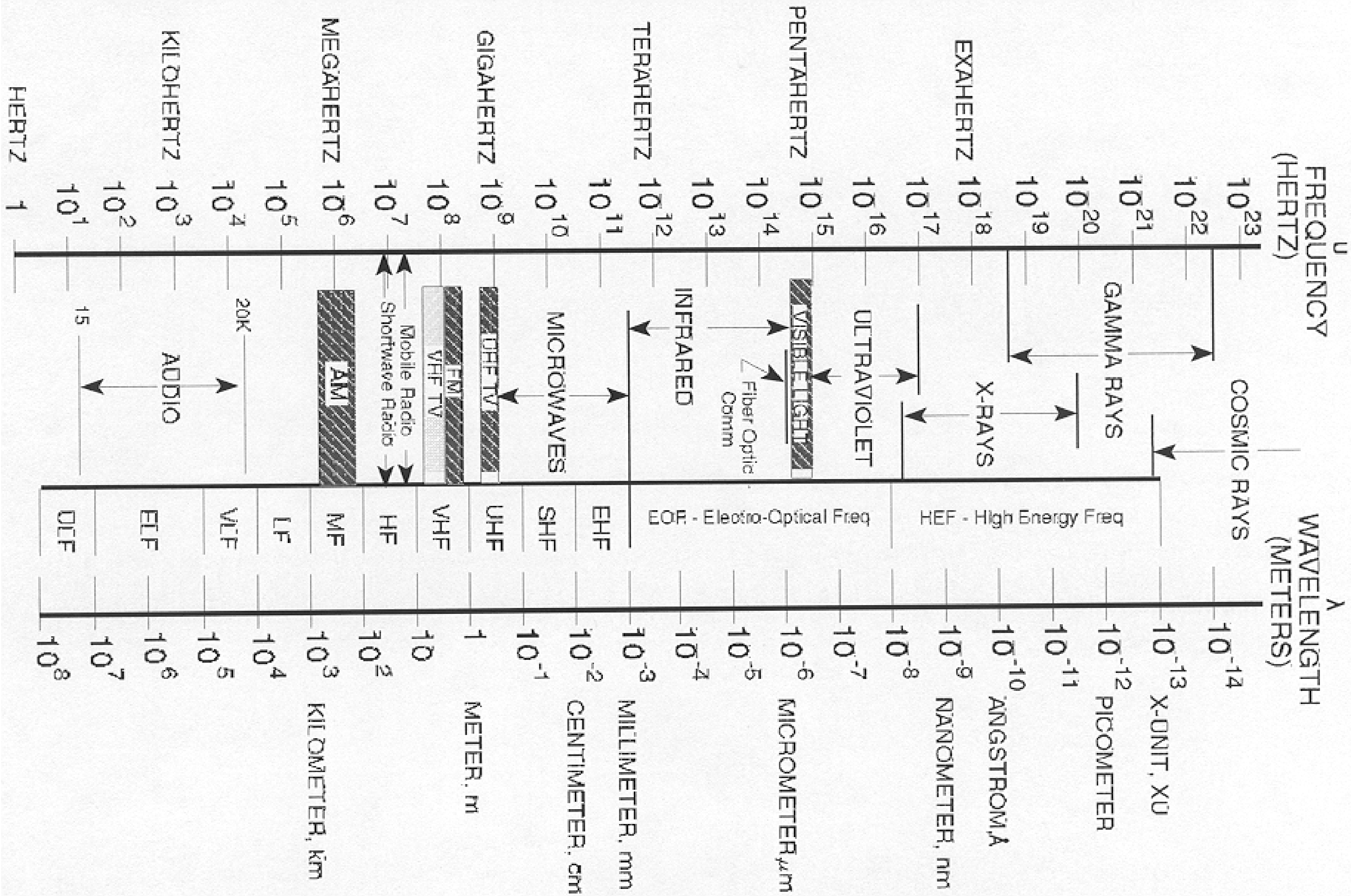
Low Frequency RF
&
Static Fields

Electromagnetic Spectrum



Sources

- Submarine ELF transmission
- Power lines

Sources of Non-Ionizing Low Frequency Radiation

- AC Generators (60 Hz for US, 50 Hz for UK)
- Submarine ELF communications
- 400 Hz and 1000 Hz communications equipment

Two Parts to Fields

- E field = Electric field strength, V/m
  - Cannot penetrate structures well
- H field = Magnetic field strength, A/m
  - Can penetrate structures well
- Both start out orthogonal but does not last long at this frequency, and become decoupled
  - True to AM wavelengths
  - Magnetic field lines are like concentric circles around conductor

60 Hz

- Tissue depth penetration = 5×10^3m
- This ELF field does not have radiating properties!!!

60 Hz AC Fields

- Energy?
- $E = hf$ (Eq. 2.75)

- 6.626×10^{-34} J·s × 60 Hz = 3.98×10^{-32} J

3.98×10^{-32} J × 1.6×10^{-19} J/eV

= 2.48×10^{-13} eV

60 Hz AC Fields

- Wavelength?

$$3 \times 10^{8}\,\frac{\mathrm{m}}{\mathrm{s}} = \lambda\,\mathrm{m} \times 60\,\mathrm{Hz}$$

- 5×10^{6} kilometers = 3.1×10^{6} miles

Energy of 100 m Wave

$c = \lambda\nu$ $\nu = c/\lambda$

$\nu = 3.00\times10^8 / 100\ m = 3.00\times10^6\ Hz$

then $E = h\nu$

$E = (4.14\times10^{-15}\ eV\cdot s) \times(3.00\times10^6\ s^{-1})$

$E = 1.24\times10^{-8}\ eV$

Energy of 12.25 cm Wave

$c = \lambda\nu \qquad \nu = c/\lambda$

$\nu = 3.00\times10^{10}$ / 12.25 cm

$\nu = 2.45\times10^{9}$ Hz

then $E = h\nu$

$E = (4.14\times10^{-15}\ \text{eV-s}) \times (2.45\times10^{9}\ \text{s}^{-1})$

$E = 1.01\times10^{-5}$ eV

Converting from E to H fields

- Converting E or H fields to S (power density)
- Not normally done for low frequency applications
  - Limits are in V/m or A/m
  - The fields are typically de-coupled at these frequencies

Safety Measurements

- Most meters read in V/m (E field) or A/m (H field).
- Typically the standard lists both
- Can use free space relationship to relate E and H fields but it is not necessarily true.

What is EM field at distances

- Do power lines follow inverse square law? Line source?
- See example 2.15 p. 30

Example

- Tom’s home has a 120 V 60 Hz supply line. The line is rated for 300 amps. At capacity, what is the magnetic field 3 meters from the breaker panel?

- Note that electric fields do not penetrate structures well

Magnetic Field Example

$$H = \frac{I}{2\pi r} = \frac{300\ \mathrm{A}}{2\pi(3\ \mathrm{m})} = 15.9\,\frac{\mathrm{A}}{\mathrm{m}}$$

$$15.9\,\frac{\mathrm{A}}{\mathrm{m}} \times \frac{1.26\ \mu\mathrm{T}}{1\,\frac{\mathrm{A}}{\mathrm{m}}} = 20.1\ \mu\mathrm{T}$$

Example

- If the ICNIRP limit for exposure to members of the public for 60 Hz is 1 G for 24 hours or less, is this limit exceeded?

$$20.1\,\mu\mathrm{T} \times \frac{T}{1\times10^{6}\ \mu\mathrm{T}} \frac{1\times10^{4}\ \mathrm{G}}{\mathrm{T}} = 0.2\,\mathrm{G}$$

Control of Hazards

- Theoretical calculations of potential fields
- Field measurements with broadband instrumentation
- Limiting access to fields above the TLV
- Time averaging and use of protective clothing and eyewear
- ALARA still a controversial issue for electromagnetic fields (0-300 GHz)

Effects of High Voltage

- Flow of current causes injury, not voltage
- Voltage available will play a role in initiating and driving the current
- Current flow is also determined by both the voltage and the electrical resistance of the body

Human Conductors

- Dry, intact skin has a high electrical resistance
  - Interior of the human body is a good conductor
  - No current flows when a relatively low voltage (~30 V) is in contact with the dry skin

Large Electrical Voltages

- Direct electrical breakdown of cell membranes by high applied electric fields
  - Large cells, such as muscle and nerve cells, are more vulnerable to electrical breakdown
  - Could cause cell damage, even if current is low

Medical Voltage Classification

- High voltage arbitrarily defined in medical community >1000 V
  – Extent of tissue damage is a function of electric-field strength, or volts per meter, along the path of the current through the body

Voltage Example One

- Consider contact with a 20,000 V electrical power line, with the contact points being the two hands.
- The distance from entrance to exit is about 2 meters and the electric field is 20,000/2 = 10,000 volts/meter.

Voltage Example Two

- A laboratory power cord (120 V) with the contact points 6 millimeters apart on one hand. The electric field is 120/0.002 =10,000 volts/meter, the same value as in the first example.

High vs Low Voltage

- The first example would be considered a high-voltage injury and the second a low-voltage injury.
- The strength of the electrical field is the same in each case and tissue damage would be similar.

Which is More Dangerous?

- The first case, because the volume of tissue involved is much larger and the path of the current is near the heart, lungs, and thorax.
  - Is potentially lethal
- Charring of the tissue at the contact points and the damage to subcutaneous tissue will be the similar in both cases.

Voltage

- Total voltage alone does not determine injury
  - localized electric-field strength determines the extent of tissue destruction
- Electric fields may damage cells through thermal injury or through electrical breakdown of cell membranes.
  - Extent of damage is dependent on the electric-field strength, NOT the total voltage.

Dosimetric Quantities for RF Radiation

- Current (*I*) and Current density (J/cm2) below 100 kHz

Biological Effects

- Electric Shock when person acts as a conductor
  - Frequency dependant

Some Human Effects

- Most susceptible thing on body: Credit cards
  - Can be “wiped” by any bulk de-gausser
  - Electronics are more susceptible than humans
  - Humans do not perturb magnetic field much
  - Need >100kHz before heating is an option with humans
    - E field causes heating at high currents at >100 kHz

Human Effects

- Coupling to body is poor at low freq.
- Induced currents major effect, can cause current to flow in body if touch radiator
  - Shock
  - Spark discharge
- Holding a co-axial cable will cause vibration (stimulation) in hand, increasing frequency will increase vibration till heating occurs at a threshold of ~100 kHz.

Effects of Frequency

- When electrical shock is from alternating current (AC)
  - Frequency plays a role when duration of the shock is more than one second.
  - Current effect is greatest from 10 Hz to 200 Hz
    - The effects, for equal current, decrease at frequencies below and above this range
    - 60-Hz electrical-line voltage is where effects are most severe

Alternating Current

- The next table presents data on the values of AC current at which muscle control is lost and one cannot let go of the current source, the let-go threshold.
- Let-go thresholds vary substantially from person to person

Let Go Thresholds (1)

- The values in the table are the values at which 50 percent of people cannot let go
  - Values for women are about two thirds of those listed in the table

Let Go Thresholds (2)

- The let-go threshold represents a level above which the victim cannot get free of the electrical source
- Above this threshold, the current continues to flow through the body, increasing the duration of the exposure and the amount of damage to the body.

Median Values of Let-Go Current

Frequency (Hz)	Let-Go Current (mA)
5	25
8	19
10	17
20	16
30	16
40	16
50	16
80	16
100	16
200	17
300	18
400	19
500	20
800	22
1000	24
2000	32
3000	38
4000	45
5000	50
8000	65
10000	75

Effects of Electric Current on the Human Body

Current (milliamperes)	Effect
1	Threshold of sensation, slight tingling
5	Slight shock, disturbing but not painful
6-25 (women) 9-30 (men)	Painful shock, loss of muscle control, inability to let go, possible burns
50-150	Severe pain, respiratory arrest, severe muscle contractions, deep burns likely, possible death
500-4000	Possible ventricular fibrillation, nerve damage, death likely
>10,000	Cardiac arrest, severe burns, death very probable

Table 10-A. Effects of Electrical Contact

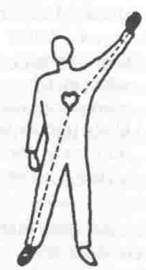
Current	Effect
Current in Amperes	
4	
3	Major burns of increasing extent and severity
2	
Current in Milliamperes	
1,000	
800	
700	Increasing risk of burns at exit and entry points
600	
500	
400	
300	
200	
100	70 to 200 milliamperes: risk of death from ventricular fibrillation if current pathway goes through heart
80	
70	
60	Risk of severe breathing difficulties
50	
40	
30	Severe shock Risk of breathing difficulties due to muscular contractions
20	
	Cannot release hand grip on conductor due to muscular contractions
10	
8	
7	Painful sensation (electric shock)
6	
5	
4	Increasingly unpleasant sensation or shock
	Mild sensation
3	
2	
1	Threshold of sensation varies from person to person and points of skin contact
0	

Ventricular fibrillation means loss of heart's pumping action, loss of pulse, and risk of death from ineffective rapid beating of heart's ventricles.

Typical current pathways for heart risk

a) Head to foot
b) Hand to opposite foot

(a)



(b)

Current levels from domestic voltages carry biggest risk of ventricular fibrillation

Source: *Canadian Occupational Safety*, January-February, 1988.

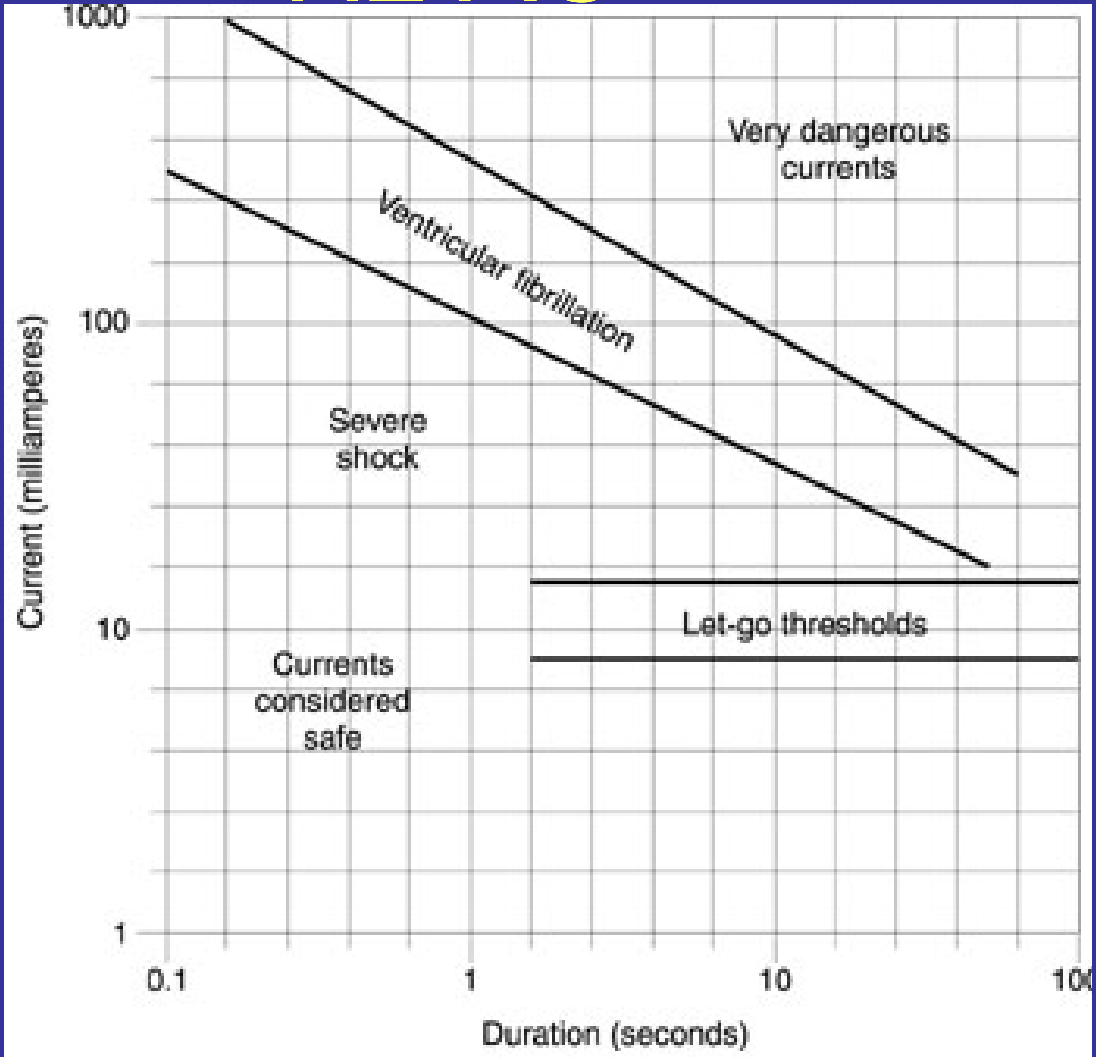
Human Resistance to Electrical Current

Body Area	Resistance in Ohms
Dry skin	100,000 to 600,000
Wet Skin	1000
Internal Body hand to foot	400 to 600
Ear to ear	100

Duration of the Shock

- Shock becomes more dangerous as it continues
  - For a given value of current, thresholds for harmful effects become lower as shock is prolonged
    - Ventricular fibrillation risk increases as shock duration increases
    - As the duration of shock lengthens from 0.1 to 100 seconds, threshold current drops by >25
  - See table for 60-cycle alternating current

Shock Duration & Ventricular Fibrillation for 60 Hz AC



OSHA Minimum Approach Distances for 60 Hz

300V and less	Avoid contact
Over 300V, not over 750V	1 ft. 0 in. (30.5cm)
Over 750, not over 2kV	1 ft. 6 in. (46cm)
Over 2kV, not over 15kV	2 ft. 0 in. (61cm)
Over 15kV, not over 37kV	3 ft. 0 in. (91cm)
Over 37kV, not over 87.5kV	3 ft. 6 in. (107cm)
Over 87.5kV, not over 121kV	4 ft. 0 in. (122cm)
Over 121kV, not over 140kV	4 ft. 6 in. (137cm)

NOTE: Unqualified employees are required to adhere to the 10 ft. minimum.

Radiofrequency (<300 MHz) Limits are Based on Electrical Current Flowing in through the Body

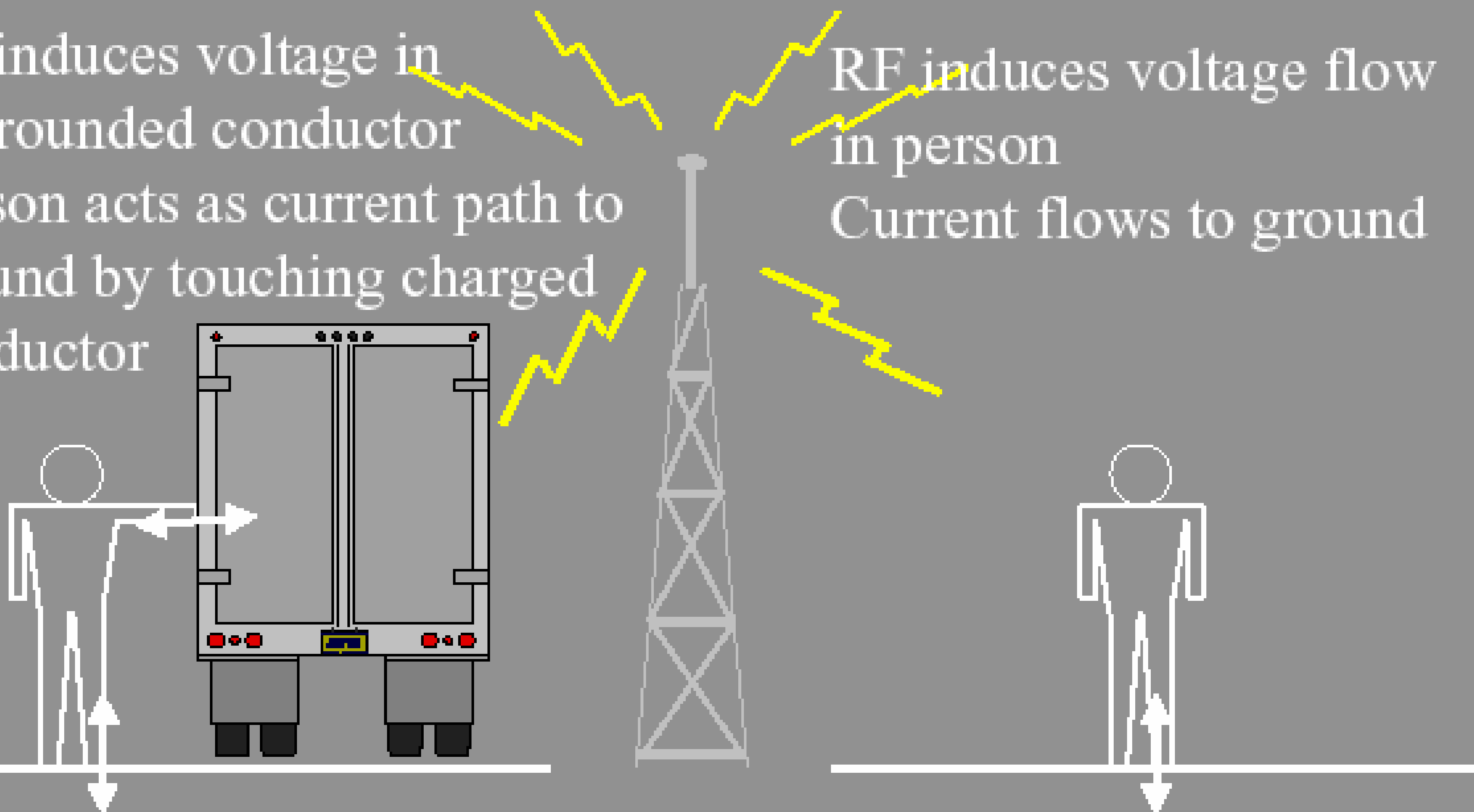
Two Scenarios:

RF induces voltage in ungrounded conductor

Person acts as current path to ground by touching charged conductor

RF induces voltage flow in person

Current flows to ground



Exposure Limits

- Limits are based on gross effects such as disruption of aortic blood flow and electrostimulation for magnetic fields and spark discharges for electric fields NOT Cancer
- Radiofrequency (<300 MHz) Limits are Based on Electrical Current Flowing through the Body

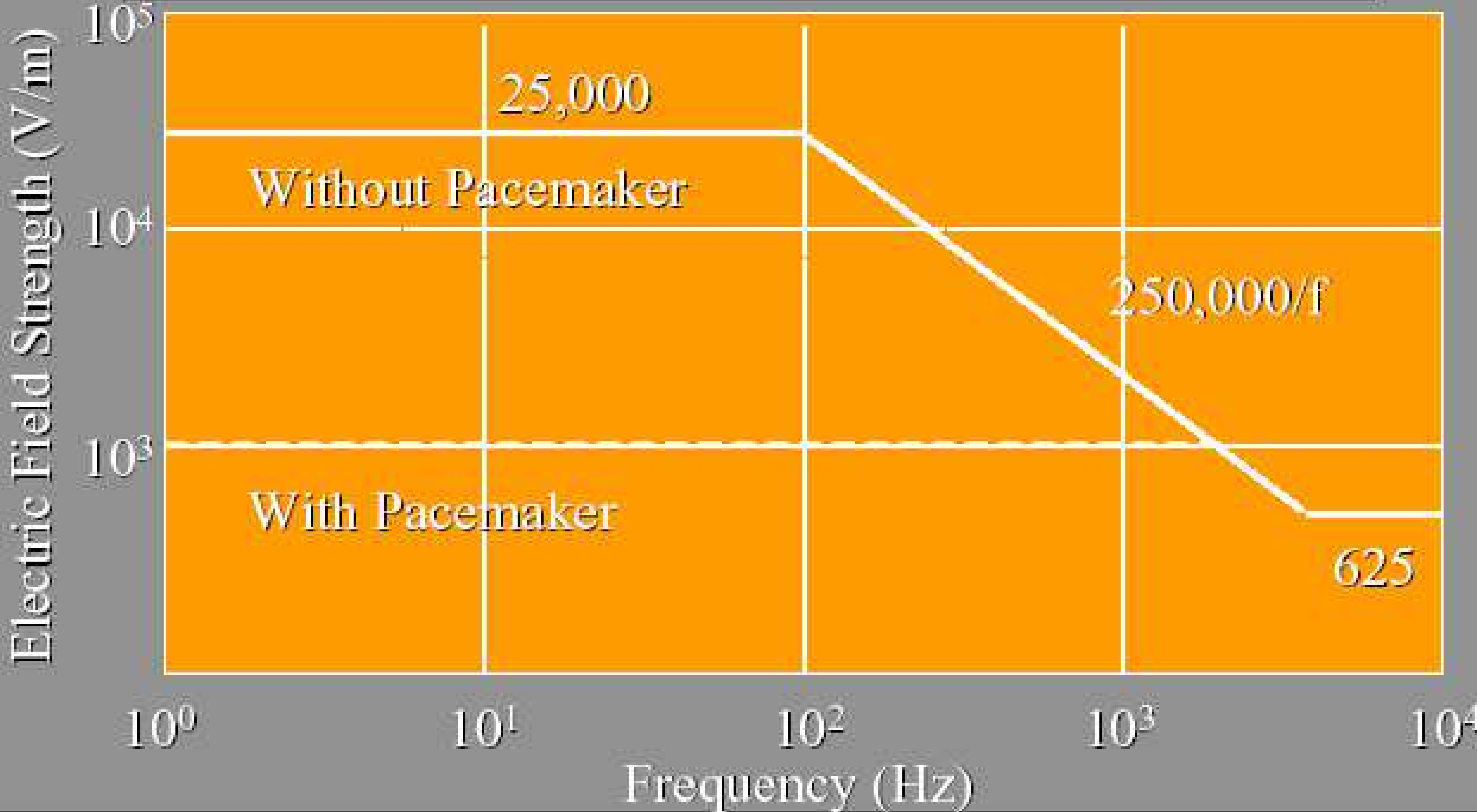
E Field ACGIH Limits

- Sub-Radio Frequency Electric
- Fields (1 Hz - 30 kHz) – ACGIH Limits
- Ceiling value for exposure of persons wearing cardiac pacemakers or other implanted medical electronic devices is 1 kV/m at power frequencies (50/60 Hz).

E Field Limits ACGIH

- $0\ \text{Hz} < f < 100\ \text{Hz}$
  - $E_{TLV} = 25$ kV/m
- $100\ \text{Hz} < f < 4000\ \text{Hz}$
  - $E_{TLV} = 2.5 \times 10^6/f$
- $4000\ \text{Hz} < f < 30\ \text{kHz}$
  - $E_{TLV} = 625$ V/m

Maximum Permissible Exposure for Sub-RF Electric Field (ACGIH)



Magnetic Fields (1 Hz - 30 kHz) -ACGIH

- Ceiling values for the ELF Range

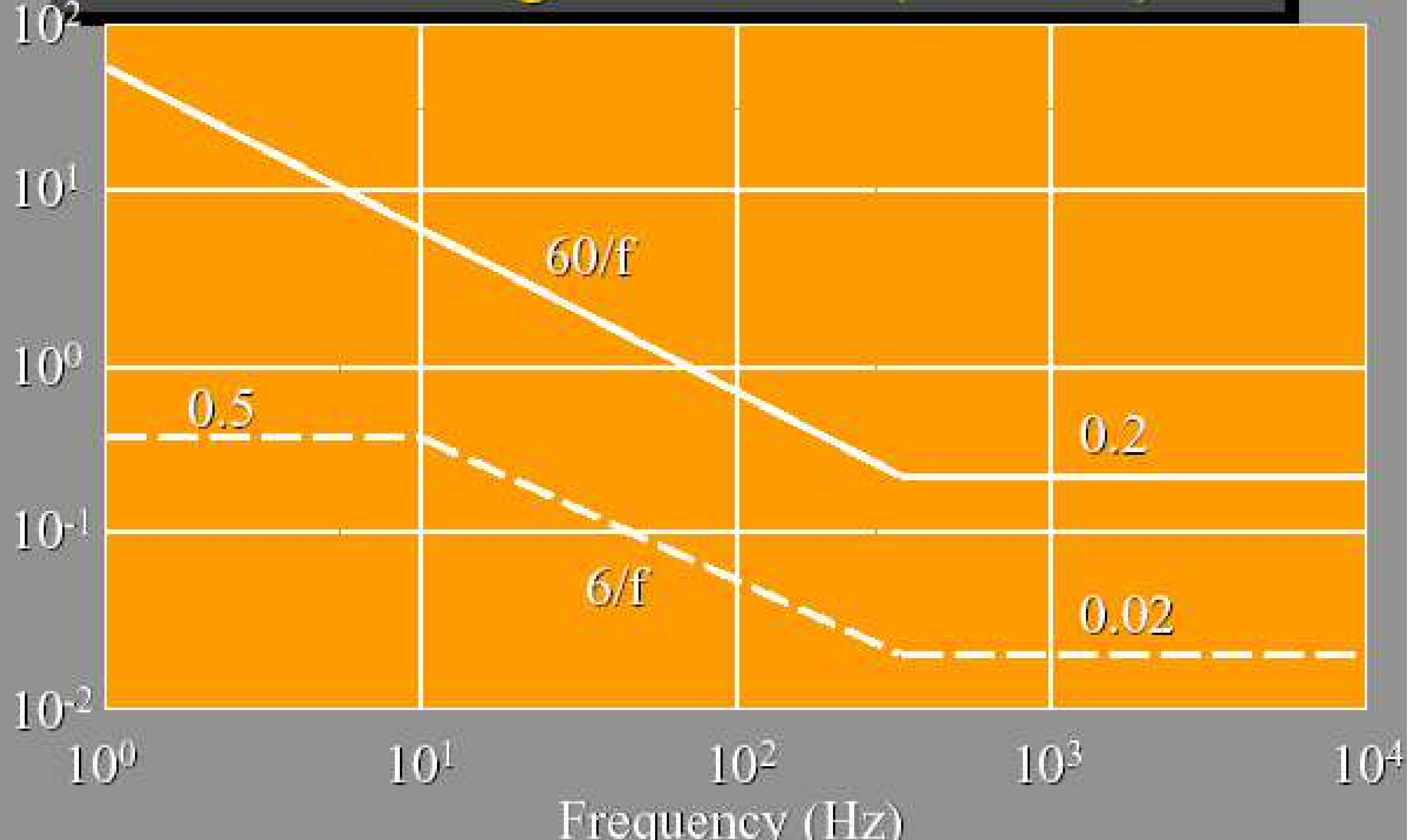
(1 Hz < f < 300 Hz),

  - B_{TLV} in mT = 60/f (with f in Hz).
  - Partial body exposures can be increased by a factor of 10 for the hands and feet and by a factor of 5 for the arms and legs.
  - Ceiling value for exposure of persons wearing cardiac pace-makers or other implanted medical electronic devices is 0.1 mT at power frequencies (50/60 Hz).

H Field ACGIH

- Ceiling values for Whole-body and Partial body Exposures, VF and VLF Range (300 Hz < f < 30 kHz),
  - B_{TLV} TLV = 0.2 mT (160 A/m)
    - Similar to IEEE C95.1 where they overlap above 3 kHz.

Maximum Permissible Exposure for Sub-RF Magnetic Field (ACGIH)



60 Hz IRPA/ICNIRP Limits

Exposure	E Field	B Field
Occupational		
Whole day	10 kV/m	5 G
Short term	30 kV/m	50 G
General Public		
< 24 hrs	5 kV/m	1 G
Few hours	10 kV/m	10 G

kV/m × hours of exposure should be less than 80 for entire day
Whole body exposure up to 2 hrs per day should be <50 G

ELF Radiation – BioEffects

Current Density (mA/m^2)	Effects (WHO, 1987)
<1	Absence of established effects
1 – 10	Minor biological effects reported
10 – 100	Well established effects, visual (magnetophosphenes) & possible nervous system effects; enhanced bone fracture repair reported
100 – 1,000	Possible health hazards; changes in central nervous system excitability; stimulation thresholds
> 1,000	Definite health hazards; extra systoles, ventricular fibrillation possible

ELF Magnetic field exposure limits: based on models relating field strength to induced tissue currents (aim: <10 mA/m^2)

ELF Radiation – ICNIRP Dose Limits

	Electric Field (kV/m)		Magnetic (G)	
Occup.	10	Continuous	50	Continuous
	30	Maximum	500	< 2 hr/day
	10	8-hr avg	2,500	Limbs only
Public	5	Continuous	10	Continuous
	5 – 10	Few hrs/day	10-100	Few hrs/day
	> 10	If current density <2 mA/m^2	>100	If current density <2 mA/m^2

[Medical Device wearers: 1 G]

Power Lines

- Electric field is relatively stable, but does not penetrate well
- Magnetic field varies with current

Non-Thermal Power Line Effects

- Cancer as a possible endpoint
  - See previous lecture on biological effects
  - Not proven
  - Biological causation?
  - Latency?
  - Measurement difficulties

60 Hz Claimed Effects

- Changes in cell function
- Decrease in hormone melatonin
- Alterations of immune system
- Accelerated tumor growth
- Changes in birythems
- Changes in brain activity and heart rate
- **NONE PROVEN**

Static Fields

- Readings
  - "Introduction to Health Physics" Chapter 2
  - "Non-Ionizing Radiation" Edited by M. Wayne Greene, p. 396-408

Sources of Static Magnetic Fields

- Earth
- Magnets
- Magnetic Resonance Imaging - MRI
- Electron Spin Resonance – ESR

Static Electric Fields (< 1 Hz)

- Earth: ~120 V/m
- Big Sources: Van de Graaf generators, Tesla coils
- Easily shielded
- Irritating Sparking ~5 kV/m; Painful at ~15kV/m
- Electrocution is primary hazard

Relationship with other Quantities and Units

- Relative permeability $\mu_r = \mu / \mu_0$
  - $\mu_0 = 4 \pi \times 10^{-7}$
- 1 Tesla (T) = 10^4 gauss (G)
- In air and tissue, $B = \mu_0 H$
- 1 A/m = 1.26 μT = 12.6 mG

Units of Magnetic Field

Quantity	Symbol	Units	Abbr.
Magnetic field strength	H	amperes/meter	A/m
Magnetic flux density	B	Tesla	T
Permeability	μ	Henries/meter	H/m
Permeability of free space	μ_0	Henries/meter	H/m

Static Magnetic Fields [<1 Hz]

- Earth: 0.4 – 0.7 G
- Big Sources: NMR & MRI facilities; also mass spectrometers, degaussers, etc.
- Difficult to shield; flows through all non-ferrous material (e.g. aluminum, plastic, people, etc.). Only attracts ferromagnetic alloys.
- Medical Device Wearers' Limit: 5 G
- ~30 G, ferromagnetic objects begin moving; projectile hazard near large magnets
- Occupational Limits: 20,000 G peak, 2,000 G 8-hr, 400 G public (ICNIRP)

Static Magnetic Fields

- Currents induced follow right hand rule
- Magnetic flux density is proportional to the magnetic field
- Magnetic fields are very directional
- Magnetic fields go through humans, most structures
  - Electric fields stopped by human body

Magnetic Fields

- B = magnetic flux density in Webers per sq. meter
- H = magnetic field strength
- μ_0 = Permeability of free space = $4\pi \times 10^{-7}$ N/A^2
- $B = H \mu_0$
- 1 unit of oersted (Oe) = 79.55 A/m

Magnetic Field Units

- 1 gauss = 80 A/m
- 1 A/m = 1.26 microTesla
- 10,000 G = 1 T
- MRI = 1 to 2 T
- Earth = 0.05 mT

Static Magnetic Fields

- Permeability = ability to magnetize
- Magnetic fields are related to current
  - Magnetic fields fall at $1/r^3$
  - Near field is not a point source

Static Field Interaction Mechanisms

- Electrodynamic interactions with ionic conduction currents
- Magneto-mechanical effects
- Effect on electron spin states

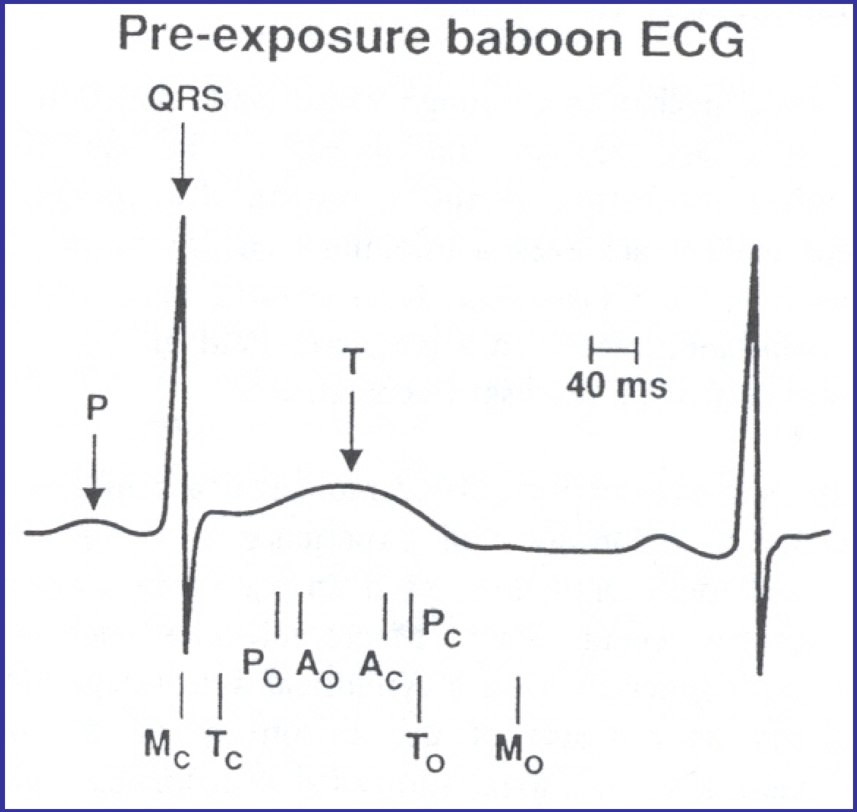
Electrodynamic Interactions

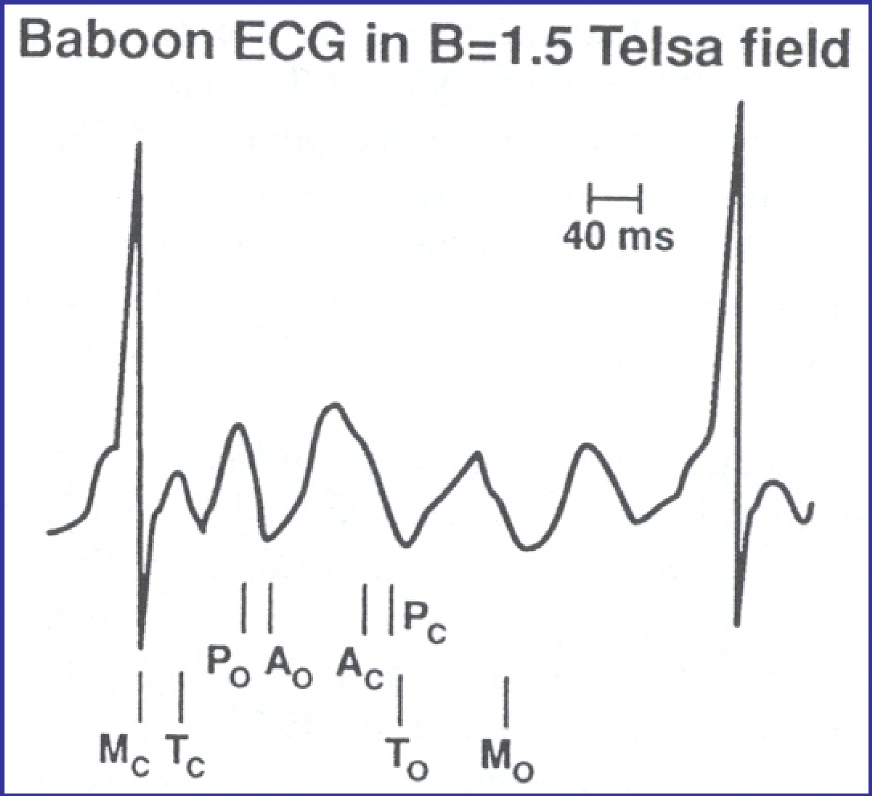
- Ionic currents interact with static magnetic fields due to Lorentz forces on moving charge carriers
- A static magnetic field >24 Tesla is required to produce a Lorentz force equal to 1/10 force from local electric fields in a nerve membrane

Ionic Fluid

- Blood flow produces significant electrical potentials at fields below 1 T
- Pulsed blood flow in aorta in the presence of a magnetic field can be detected in an electrocardiogram.

Magnetic Field Effects on EKG





Note pulsations appear from blood flow when magnetic field applied

Magnetic Forces on Electrolyte Solutions

- Magnetic forces on electrolytes such as blood, will cause a net reduction in flow velocity, due to ionic conduction current density as a result of the induced electric filed in the solution
- Not measurable at up to 1.5 T, can only be calculated

Magnetomechanical Interactions

- Two types of forces
  - Rotational motion in a uniform field until minimum energy state achieved
  - Translational force on paramagnetic or ferromagnetic substances

Magneto-Orientation

- Rotation of of molecules that have a unequal distribution of charges, or have a charge at one end, to orient themselves with the external magnetic field (DNA)
- Rate and degree of rotation depends on magnetic field, thermal energy, molecular volume, and magnetic susceptibility

Magneto-Orientation (2)

- A field of 13 T is required to produce 1% orientation of calf thymus DNA molecules
- Structures requiring less than 1 T in vitro
  - Retina rod outer segments, Muscle fibers, filamentous virus fibers
  - Not shown in vivo up to 1.5 T
- Intact deoxygenated sickled erythrocytes align in 0.35 T field with long axis of cell perpendicular to magnetic flux

Translation of Substances

- Used to target drugs encapsulated in magnetic microcarriers
- Separation of deoxygenated erythrocytes from whole blood
- Separation of anti-body secreting cells from a suspension of bone marrow

Spin States

- External magnetic fields can influence spin states of organic chemicals and influence reaction at as low a 1 mT
- Chemical reactions involving free radicals, or radicals can typically be influenced by magnetic fields interfering with spin states, changing lifetimes of radicals
  - Shortening them significantly

MRI and ESR

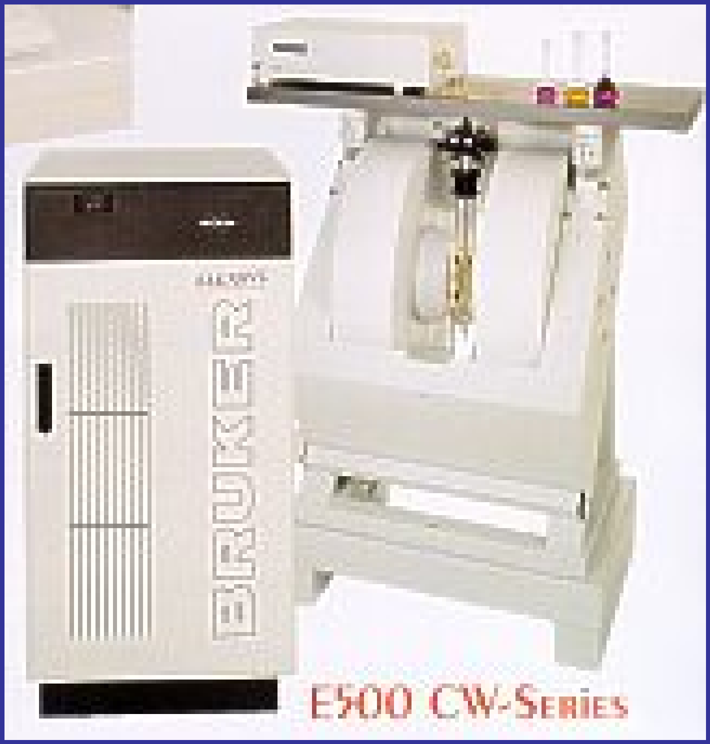
- Both rely on external magnetic fields influencing spin states

MRI

Magnets

- MRI = Usually 1 T magnets
- 4 T magnets generally threshold for nausea, dizziness, metalic taste, magnetophosphenes
- Magnetohydrodynamic voltage (MHD)

ESR



Unique Sensitivities to Magnetic fields

- Elasmobranch Fish
- Magnetelectric Bacteria

Elasmobranch Fish

- Sharks, Skates, Rays
  - Heads contain long jelly filled canals with high electrical conductivity
    - Ampullae of Lorenzini
  - Swimming through lines of geomagnetic flux induces small voltage gradients
  - Can be detected at < 0.5 microV/m by sensory epithelia in the terminal ampullary region
  - Provides directional clues to fish
    - See Science, 218;916-918:1982

Magnetotactic Bacteria

- Responds to geomagnetic field
- Approximately 2% of cell dry mass is iron
- Chains of 20 to 30 magnetite crystals in membrane structures in cell
- Northern hemisphere bacteria migrate north, southern, south. Equator, equal mix
- Migrate downwards in response to vertical component of geomagnetic field
- Stop migrating when mud/water interface field is zero

Other Sensitive Organisms

- In dispute if pigeons can detect geo magnetic fields and if use to navigate
- Magnatite domains in bees, dolphins, tuna, salmon, turtles, and humans. Some claim sensitivity of them, but results negative thus far.

Lightning

- Over 1,000 people get struck by lightning every year in the U.S.
  - 100 of them die as a result of the strike.
- Up to 50,000 V/m

Outside in a storm

- Seek APPROPRIATE shelter.
  - Lightning can use humans as a path to the earth just as easily as any other object.
  - Appropriate shelter would be a building or a car.
  - Avoid taking shelter under trees.

Safety in a Storm

- Put your feet as close together as possible and crouch down with your head as low as possible without touching the ground.
- Never lay down on the ground.

After Lightning Strikes the Ground

- An electric potential radiates outward from the point of contact.
  - If your body is in this area, current can flow through you.

Should I Really Stay off the Phone?

- If you are indoors, stay off the phone!
- If you must call someone, use a cordless or cell phone.
- If lightning strikes the phone line the strike will travel to every phone on the line
  - and potentially to you if you are holding the phone!

Plumbing

- Stay away from plumbing pipes (bath tub, shower, etc).
- Lightning has the ability to strike a house or near a house and impart an electrical charge on the metal pipes used for plumbing.
- This threat is not as great as it used to be, because PVC is now used often for indoor plumbing.

Safe from Lightning in a Car?

- Rubber tires keep you safe in a car because they do not conduct electricity.
  - NO!
  - In strong electric fields, rubber tires actually become more conductive than insulating!

Safe in a Car Because...

- Lightning will travel around the surface of the vehicle and then go to ground.
- The vehicle acts like a Faraday Cage.
  - a metal cage would shield objects within the cage when a high potential discharge hit the cage.
  - The metal directs the current around the objects and discharge it safely to the ground.
- This process of shielding is used today to protect the electrostatic sensitive integrated circuits in the electronics world.

Will Surge Protectors Save My Electronics?

- NO! Your TV, VCR, communications equipment will be destroyed.
  - Surge protectors provide protection for power surges in the line from the power company, not for lightning.
- Need a lightning arrester to stop lighting damage.

Lightning Arrester

- Arrester has a gas filled gap that acts as an open circuit to low potentials, but becomes ionized and conducts at very high potentials.
- When lightning hits the line, the gas gap will conduct the current safely to the ground.

Lightning Injury Facts
"I will probably never treat a victim of a lightning injury in my practice because they are so rare. "

False.

- Electrical injuries are more common than lightning injuries BUT:
- Best estimates place lightning injuries at somewhere between several hundred and a few thousand per year

Lightning Victims

- Typically avoid medical care initially, hoping that the symptoms will subside in a few hours or days.
- Most are not admitted to the hospital and thus do not become part of any state hospital admission databank.

"I will probably never treat a victim of a lightning injury in my practice because no one lives to tell about it."

False

- Only 20 to 30% mortality.
  - Studies have probably overestimated the mortality
- Between 75 and 150 reported deaths per year (and many do not get coded appropriately), there may be as many as 750 to 5000 lightning injuries per year.

"Nowadays most lightning injuries occur on the golf course. "

False

- Most are work-related!
- Majority are postal and construction workers and persons using telephones that have not been properly grounded.
- The numbers of farmers injured has decreased
  - work larger fields in better-protected vehicles.

Injuries During Recreation

- Increasing in number.
  - Joggers, hikers, and campers, as well as golfers.
- In addition, a significant number of people are injured while participating in team sports.

Type of Injuries

- Commonly lightning and electrical injury causes impotence, as a result of either direct nerve or spinal cord injury or depression.
- The victim struck by lightning does not burst into flames/reduced to a pile of ashes.
- Lightning often flashes over the outside of a victim, sometimes blowing off the clothes but leaving few external signs of injury and few, if any, burns.

Crispy Critter

- "If you're not killed by lightning you will be OK”
- "If there are no outward signs of lightning injury, the injury can't be serious”
  - In the last few years, it has become apparent that permanent sequelae may often occur lightning and electrical victims with significant sequelae may have no evidence of burns.

High Voltage Personality

- A myth that is still prevalent today is that the victim of lightning retains the charge and is dangerous to touch, since he is still "electrified "
- This idea has led to unnecessary deaths because of delaying resuscitation efforts.

PPE?

- "Wearing a rubber raincoat (substitute sneakers or other forms of clothing here) will decrease my chances of being hit."
- "Wearing cleated shoes increases my chances of being struck."

False

- If lightning has burned its way through a mile or more of air a few millimeters of any insulating material will be immaterial
- Metal on the bottom of the feet can heat up and cause secondary burns, but it is unlikely to "draw" lightning to the person.

DC Current Effects

Current in milliamperes	Direct Current	
	Men	Women
Slight sensation on hand	1	0.6
Perception Threshold	5.2	3.5
Shock-not painful, muscular control not lost	9	6
Shock-painful, muscular control not lost	62	41
Shock -painful, let-go threshold	76	51
Shock-painful and severe, muscular contractions, breathing difficult	90	60
Shock-possible ventricular fibrillation effect from 3-second shocks.	500	500

Capacitors

- Capacitors may still contain energy even equipment is de-energized
- They are often charged to voltages of several kilovolts and store energies from hundreds to thousands of joules.

Capacitors

- If a person comes in contact with such a capacitor, it is possible that its entire stored energy may discharge through the victim.
- Can hold their charge for up to years

Handling Capacitors

- Energy-discharge capacitors should be enclosed in a well-grounded, locked metal enclosure, which should be designed to prevent accidental contact with any of the conductors inside it.
  - Provide for automatic discharge of the capacitors before any access door is opened.
  - This is done by shorting or grounding the capacitors with a heavy-duty conductor.
    - ("crow-barring the capacitors")

Capacitors

- The crowbar should be able to withstand the large currents that flow and the large mechanical forces that will be exerted on it.
- Shorting straps should be placed on the capacitors before any maintenance work is done.
- Workers should wait 24 hours after the capacitors have been crow-barred before beginning work on that circuit.
- Be sure each capacitor is discharged, shorted, and grounded before beginning work.

Capacitor Example

- Assume a 500 microfarad capacitor is in a system and the resistance of the body after the skin is broken down is 500 ohms
  - (a typical value for the resistance of the body between major limbs).
- The time for capacitor to discharge = 500 μs
- The capacitor is rated at 480 V

Capacitor

- Calculate the number of coulombs available from this capacitor
  - Charge = capacitance × voltage

    500×10^{-6} F × 480 V = 0.24 coulombs

    (Cember, equation 2.66)
- Calculate the current across the person

$$\frac{0.24\,\mathrm{C}}{500\times10^{-6}\,\mathrm{s}} = 480\,\mathrm{A}$$

Capacitor Energy

- Calculate the energy involved in the current flowing across the persons limbs
- Voltage × charge = joules
- 480 V × 0.24 C = 115.2 J

Capacitor Energy (2)

- Assuming the specific heat of a human is 1 cal/g-C°, and there are 4.186 J/cal, what is the temperature rise if the energy is deposited a track that contains a total mass of approximately 0.1 g?

$$\frac{115.2\ \mathrm{J}}{0.1\ \mathrm{g}}\left(\frac{\mathrm{g}\cdot{}^{\mathrm{o}}\mathrm{C}}{1\ \mathrm{cal}}\times\frac{\mathrm{cal}}{4.816\ \mathrm{J}}\right)=239.2^{\mathrm{o}}\mathrm{C}$$

Static Field Hazards

- Physical, from metallic objects becoming projectiles in presence of large magnets
- Implanted metal devices
- Capacitors
- Lightning

Large Static Magnetic Fields

- Static Fields of 1 T or higher the following are NOT altered:
  - Cell Growth
  - DNA structure and gene expression
  - Reproduction and development
  - Visual function
  - Nerve activity
  - Cardiovascular dynamics
  - Hematological indices
  - Immune Response
  - Physiological regulation and circadian rhythms
  - Animal behavior

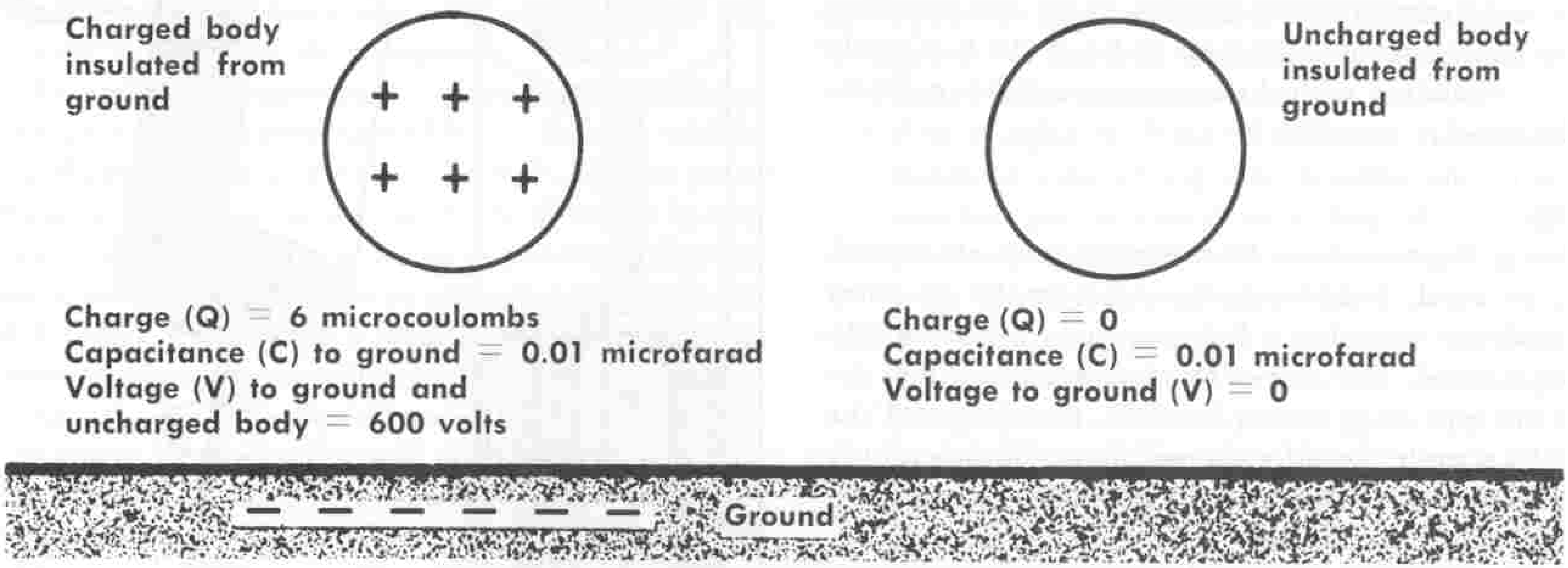
Human Health Effects

- Epidemiological studies have shown no adverse effects to date
- Medical electronic devices most important adverse effect
- Limits based on gross effects such as disruption of aortic blood flow and spark discharge
  - Spark from rug ~15000 V/m

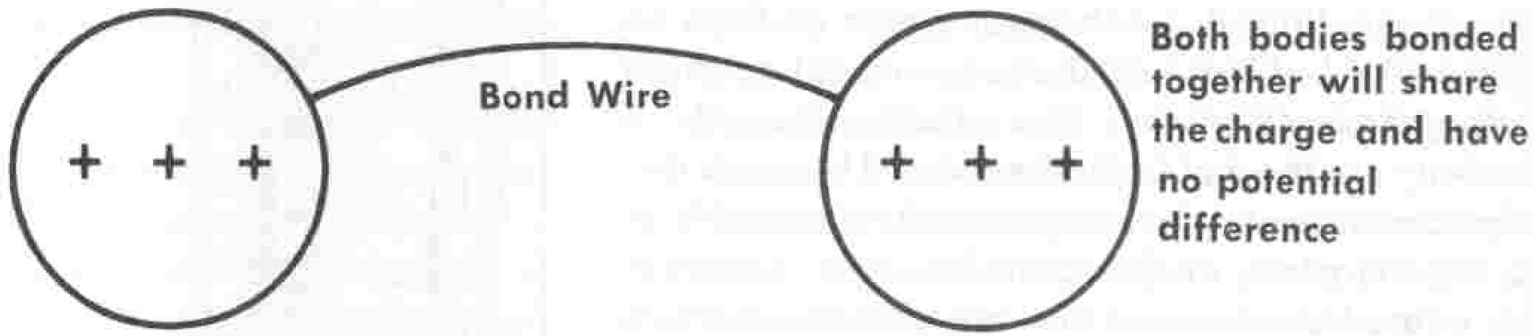
Safety

- Static field TLV from ACGIH
  - Magnetic Field Occupational Limits
    - Daily whole body exposure = 600 G (60 mT)
    - Ceiling for Whole Body = 20,000 G = 2 T
    - Ceiling for limbs = 600 G (0.6 T)
    - Pacemakers and other implanted devices = 5 G (0.5 mT)
      - 1.7 mT can close reed switch for asynchronous operation
  - Electric Field Limits
    - 25 kV/m from 0 to 100 Hz
      - Workers with pacemakers 1 kV/m
    - Use protective devices in fields above 15 kV/m

CHARGED AND UNCHARGED BODIES INSULATED FROM GROUND

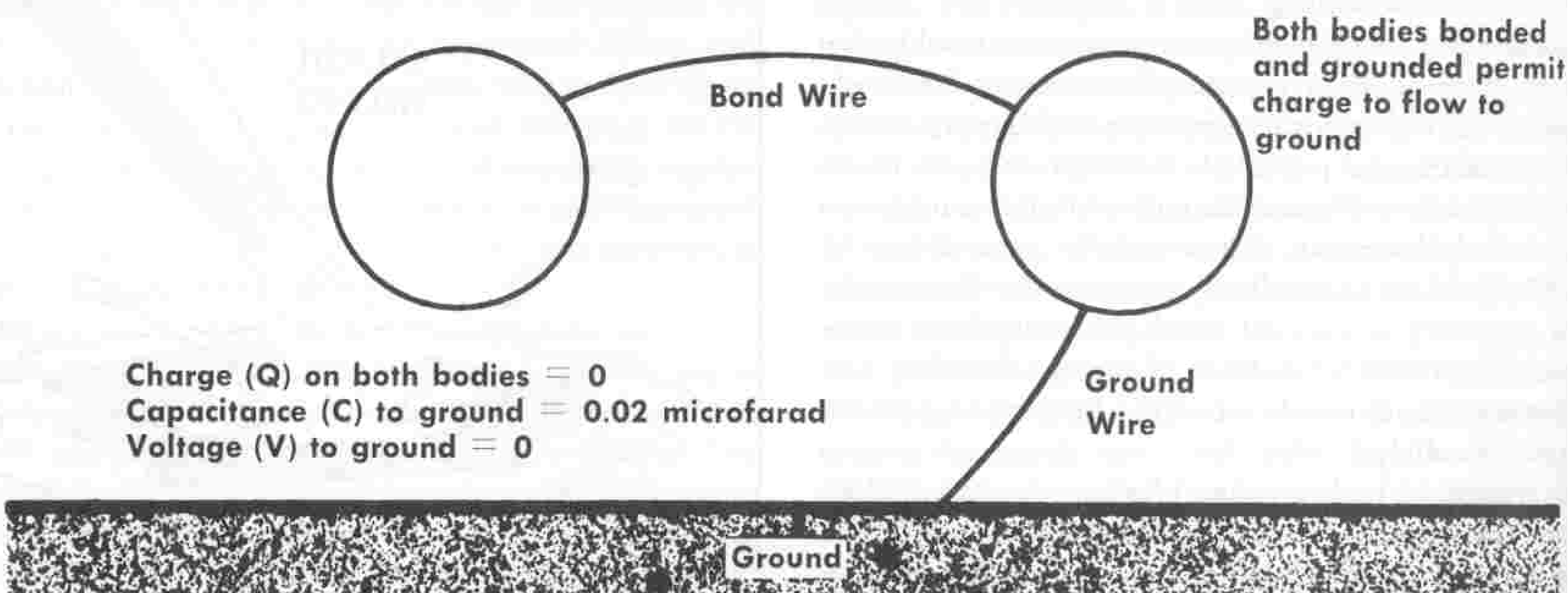


BOTH INSULATED BODIES SHARE THE SAME CHARGE



Charge (Q) on both bodies = 6 microcoulombs
Capacitance (C) to ground for both bodies = 0.02 microfarad
Voltage (V) to ground = 300 volts

BOTH BODIES ARE GROUNDED AND HAVE NO CHARGE



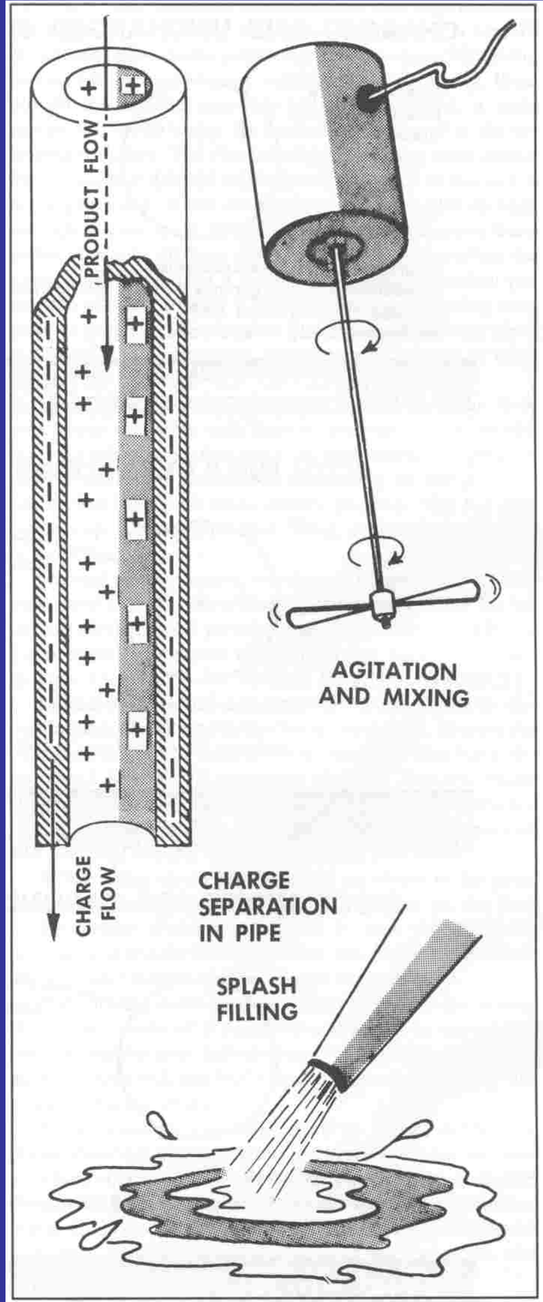


Figure 12-1. These are typical static-producing situations, including charge separation occurring in pipes.

References

- Static Fields:
- Non-Ionizing Radiation, Edited by Wayne Greene, p. 396-413, 1992

References

- National Electric Safety Foundation
  - http://www.nesf.org
- OSHA
  - http://www.osha-slc.gov/SLTC/electrical/index.html
- Photos courtesy of: Joe Tedesco, NTT, Inc., www.joetedesco.com
- http://www.Electrical-Contractor.net/Lightning_Safety_Page.htm

References

- http://cord.org/cm/leot/course04_mod01/mod04_01.htm
- Myths, Miracles, and Mirages, Mary Ann Cooper, MD, An article about both lightning and electrical injuries: Seminars in Neurology, Volume 15, Number 4, December 1995

Relevant Standards

- IEEE/ANSI C95.1Standard for Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to 300 GHz
  • ICNIRP Standard - 1998 (1 Hz to 300 GHz)
  • OSHA (29 CFR 1910.97)
  • NRPB (UK) Revised Recommendation 4.5, 1993

References

- Accident Prevention Manual, National Safety Council, 1997
- Questions and Answers about EMF, National Institutes of Environmental Health Sciences, January 1995