# Static Magnetic Fields:

## Effects / Volumes / Forces / Harms

Tobias Gilk - September 26, 2022

# Rules of the Road

- Everything on the screen is for you (you can copy or take photos).
- If you have questions, ask!
- If you disagree, please speak up.

# Outline

## Static Magnetic Fields

- Intro
- Fields / Distributions / Units
- Magnets, Magnetism, & Magnetic Materials
- Physical Forces / Bioeffects
- Implant Scenarios
- Q & A

*“If you don’t know what you’re exposing a patient (or device) to, you can’t begin to perform an MR risk-assessment.”*

**— Me**

# Static Magnetic Field

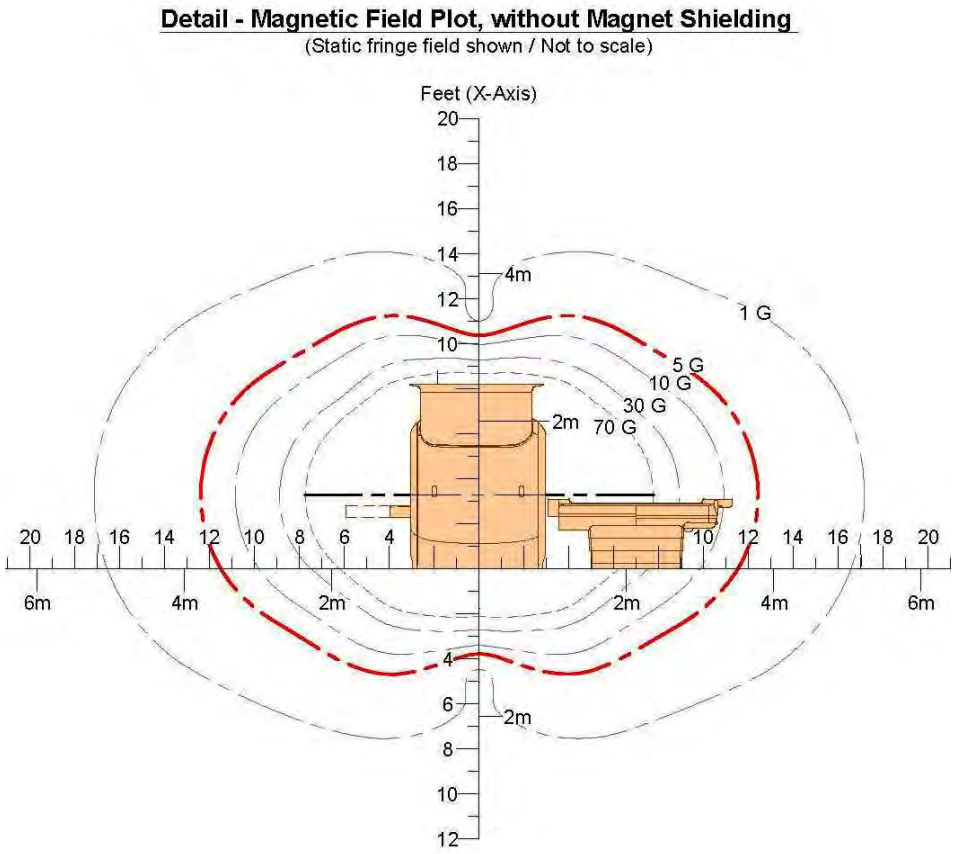
## Recap & Advance

- When & Where
- Field Strength (B0) & Spatial Field Gradient (SFG)
- Units & Measures
- Plots & Graphs
- Physical Effects
- Physiologic Effects

# Static Magnetic Field

## When & Where?

- Always On
- Increases w/ Proximity
  (max usually near mouth of bore)
- Magnetism Not Contained By
  Conventional Construction



# Static Magnetic Field

## Modes

### Normal Mode

- 0T ≦ 4T

### First Level Controlled Operating Mode

- 4T ≦ 8T

### Second Level Controlled Operating Mode

- > 8T

**201.3.208**
**FIRST LEVEL CONTROLLED OPERATING MODE**
mode of operation of the MR EQUIPMENT in which one or more outputs reach a value that can cause physiological stress to PATIENTS which needs to be controlled by MEDICAL SUPERVISION

# Static Magnetic Field

## Field Strength & SFG

### Field Strength

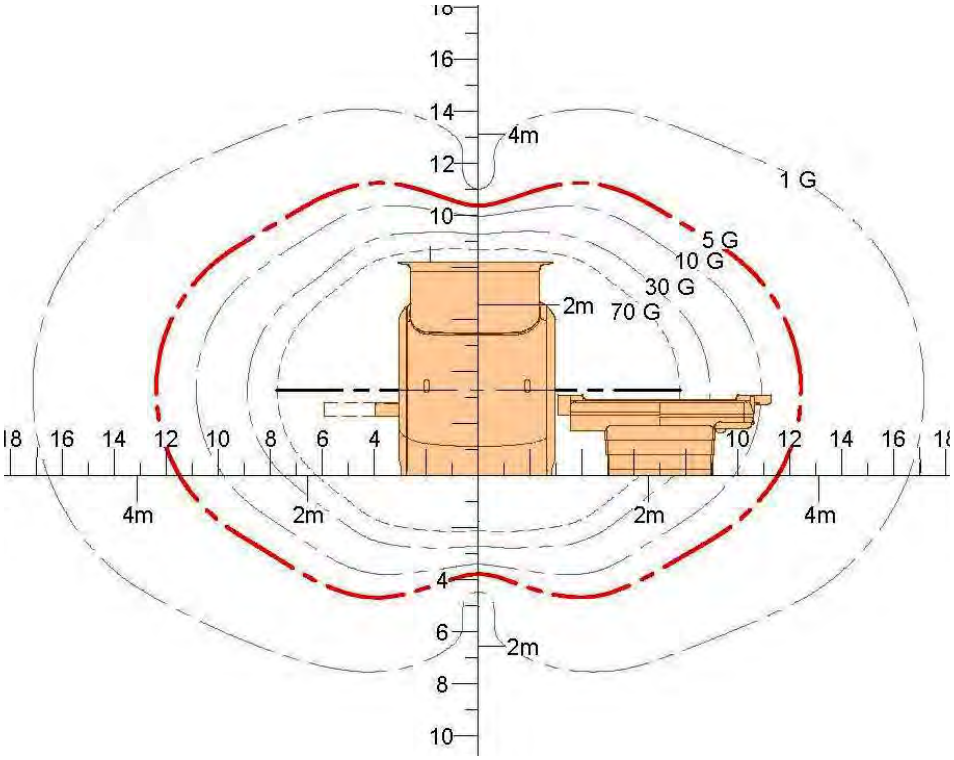
- Single-Factor Measure
- ‘Nominal’ Field Strength (e.g., “1.5 T” or “3.0 T”)
- Fringe Field Strengths (e.g., 5 Gauss, 100 Gauss)

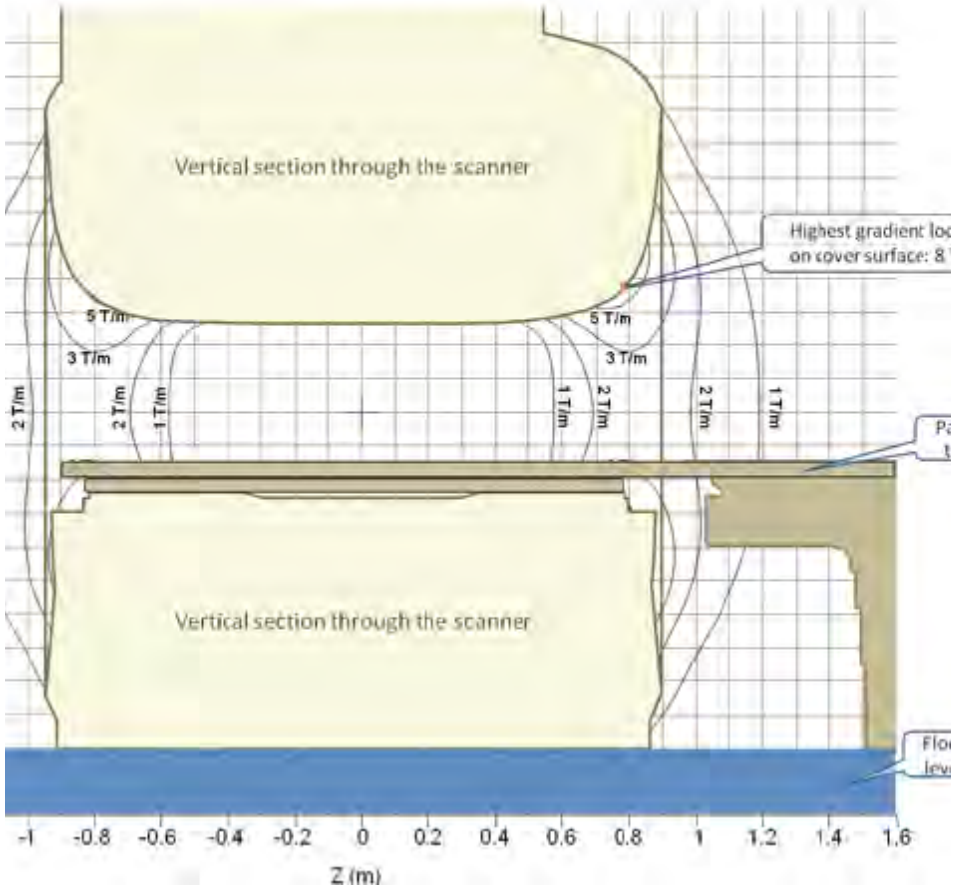
### Spatial Field Gradient

- Two-Factor Measure
- Change In Field Strength Over Distance
- “Steepness” Of Magnetic Field
- Depicted in G/cm or T/m

# Static Magnetic Field

## Plots & Graphs

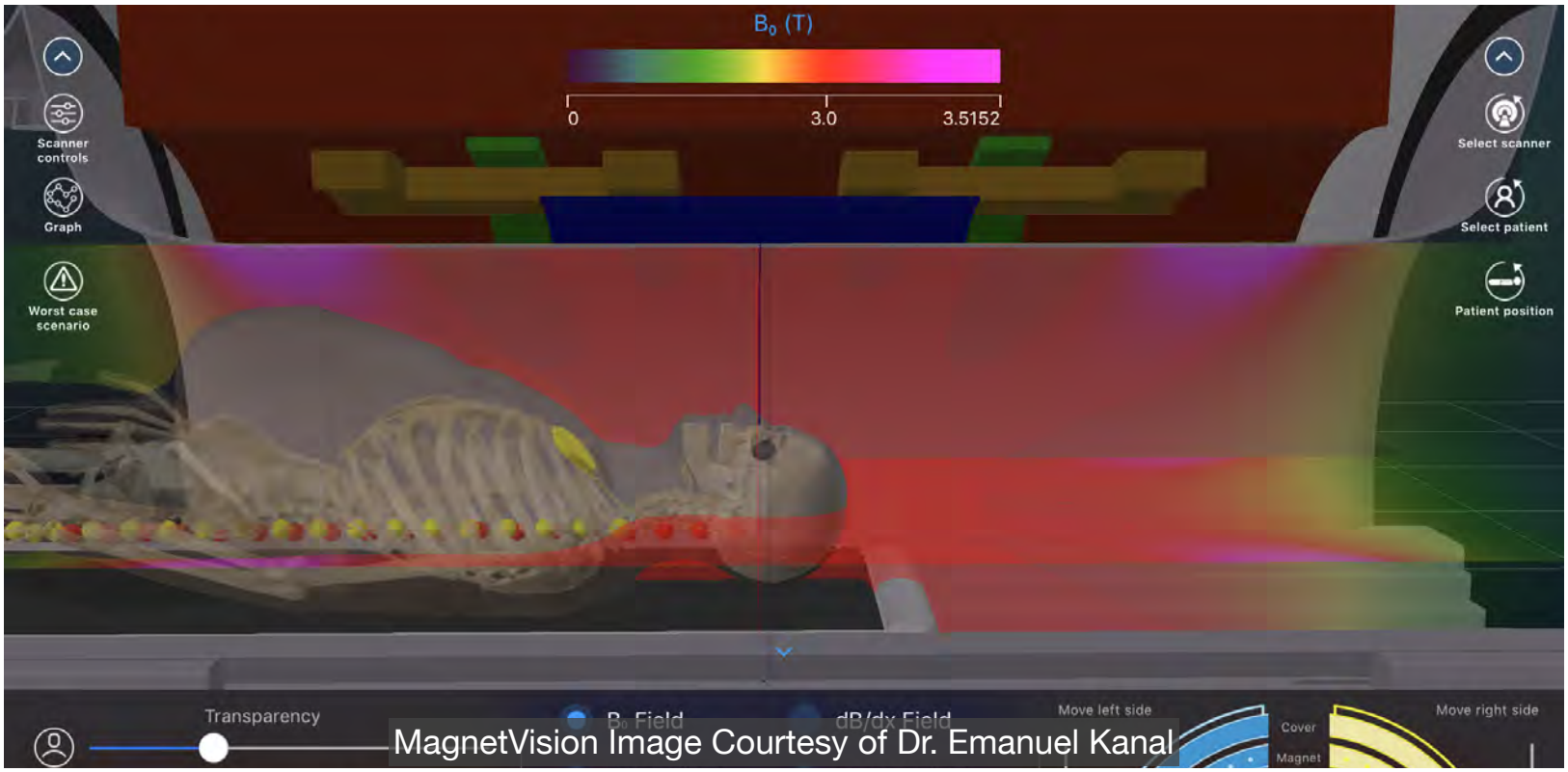


# Static Magnetic Field

## Plots & Graphs

B0 Magnetic Field Strength

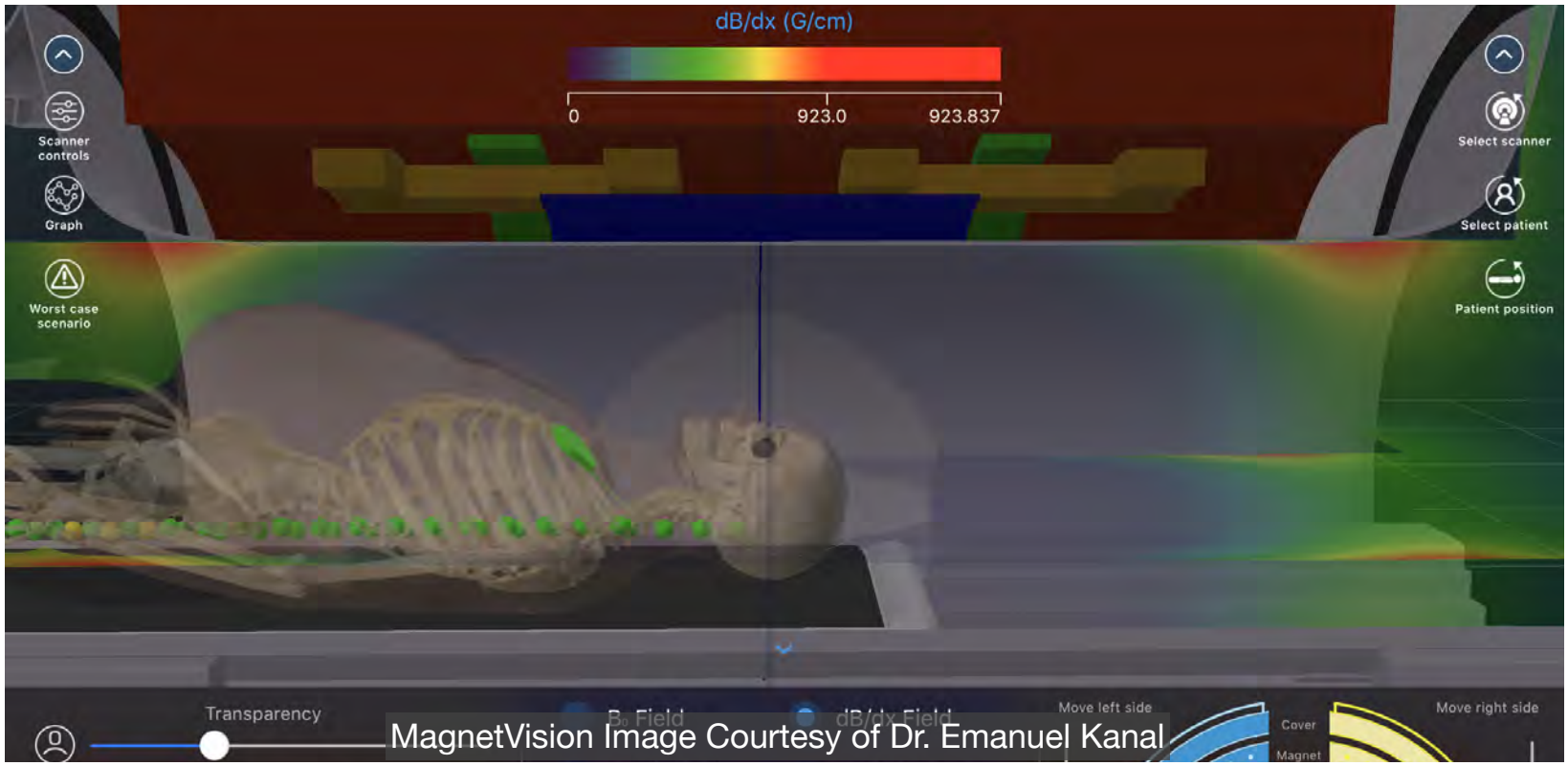



MagnetVision Image Courtesy of Dr. Emanuel Kanal

# Static Magnetic Field

## Plots & Graphs

Spatial Field Gradient




MagnetVision Image Courtesy of Dr. Emanuel Kanal

# Static Magnetic Field

## Magnets / Magnetism / Magnetic Materials

# Static Magnetic Field

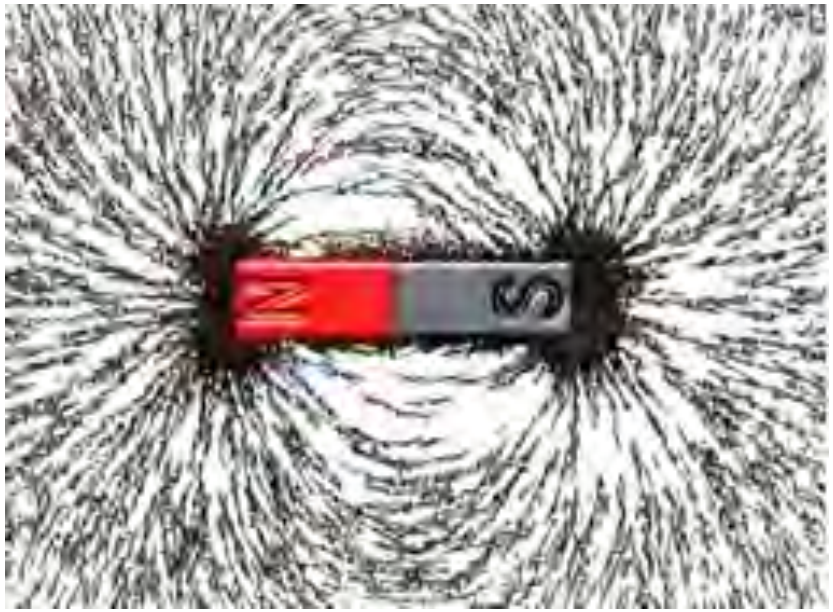
## Magnets & Magnetism

- Poles
- Orbital Path (not ray)
- Flux Density

# Static Magnetic Field

## Magnetic Poles

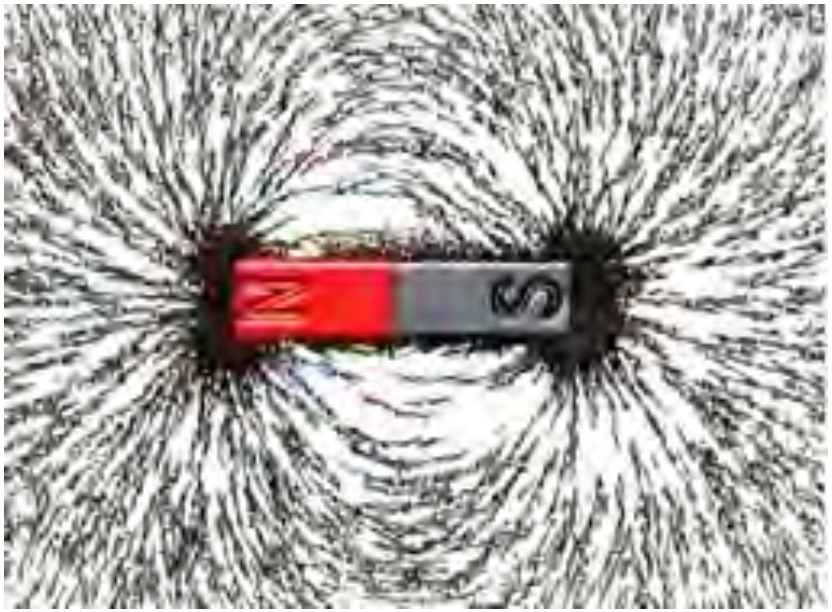
- Magnetic Energy Travels From One Magnetic Pole to The Other

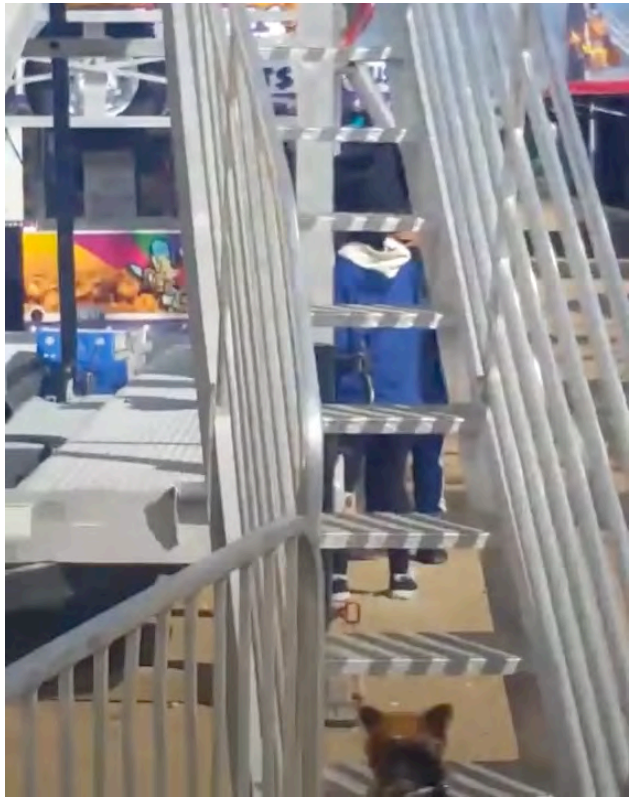


# Static Magnetic Field

## Magnetic Orbital Path

- Magnetism takes an Orbital Path

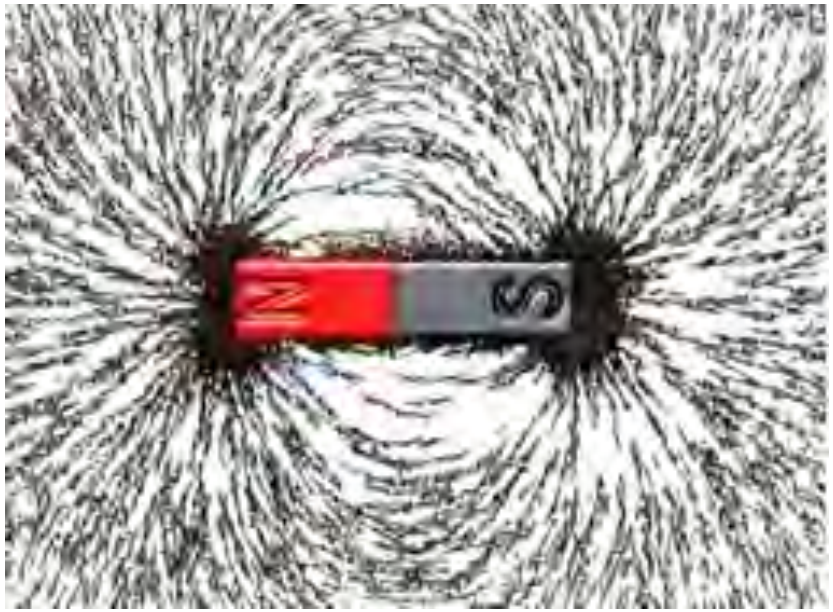


# Static Magnetic Field

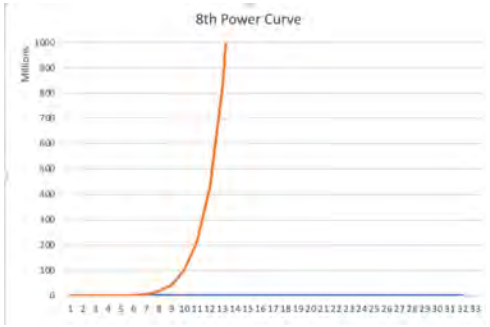
## Magnetic Flux Density

- What We Measure As Field Strength Is The Density of Those Orbits



# Static Magnetic Field

## Inverse-Square ($X^{-2}$) Law?




- Simple Magnet (e.g., bar magnet) —> Inverse-Cube ($X^{-3}$)
- Actively-Shielded MRI —> Inverse-Fifth ($X^{-5}$)

- Simple Magnet *Interacting With* Actively-Shielded MRI

  $(X^{-5}) + (X^{-3}) = (X^{-8})$

If Interaction Field Strength Is 100 Gauss at 1m, What Is It At 0.5m?

$2^8 = 256$ 256 x 100 Gauss = 2.56 Tesla

# Static Magnetic Field

## Magnetic Materials

- Ferromagnetic / Paramagnetic / Diamagnetic
  - Iron-Filings / Magnetic ‘Domains’
- Stainless Steel
  - Ferritic
  - Austinitic
- Materials Frequently Found in Implants
  - Nitinol, 316L Stainless, Titanium Alloys (CP)

# Static Magnetic Field

## Physical & Physiological Effects

# Static Magnetic Field

## Physical Effects

- Torque / Rotation (Function of B0)
- Translation / Attraction (Primarily Function of SFG)
- Lenz Force (Faraday's Law of Induction)

# Static Magnetic Field

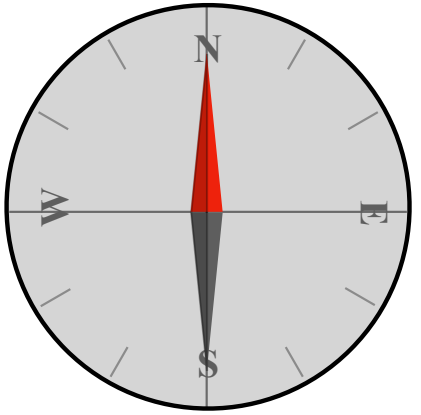
## Torque

- ‘Magnetizability’ of Object
- Length of Object
- Orientation of Object (relative to magnetic field)
  - Vertical Field Magnets

# Static Magnetic Field

## Torque - Magnetizability

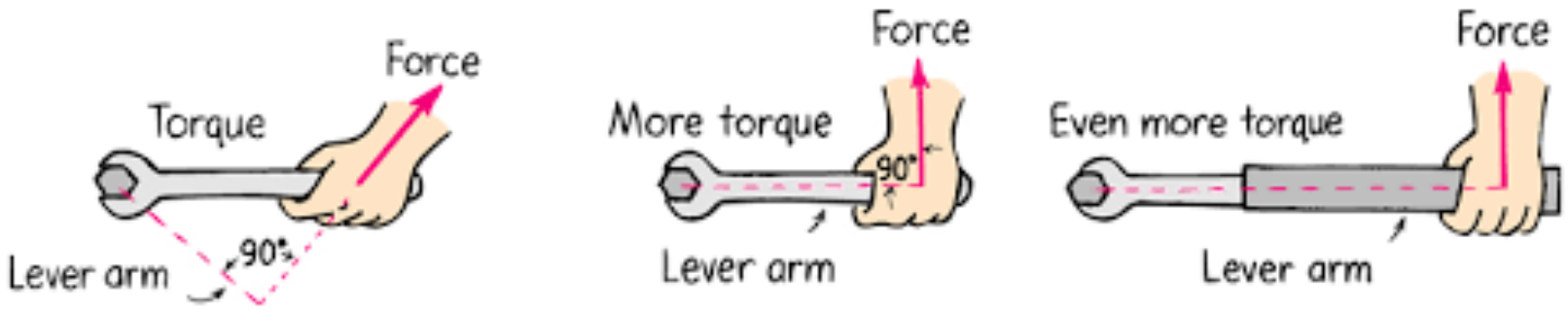
- Anyone Who Has Played With Magnets Know Some Materials Are Magnetizable, Some Are Not.
- Torque Requires Magnetizable Materials
  - Such As: Iron, Nickel, Cobalt (and many of their alloys)
  - Not: Copper, Brass, Aluminum, Titanium



# Static Magnetic Field

## Torque - Length

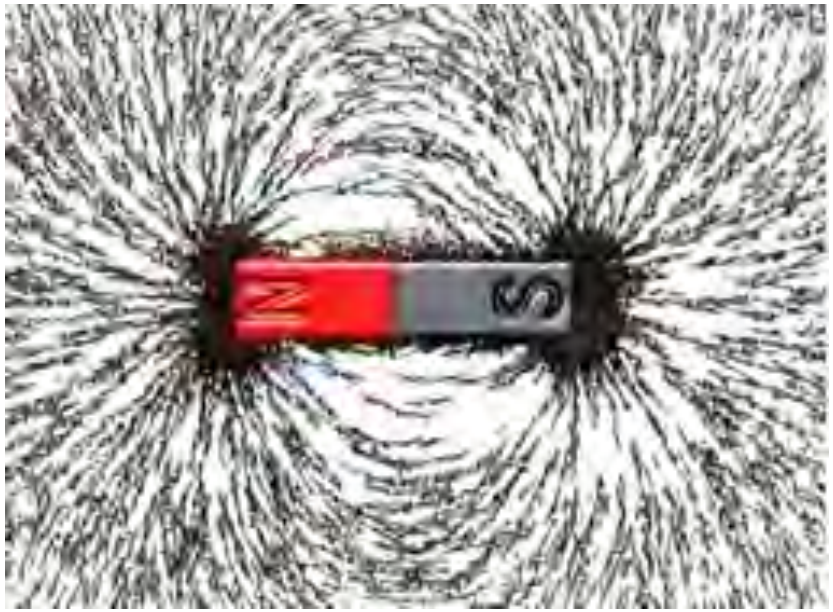
- The Longer (Less Sphere-Like) An Object Is, The More Torque It Can Produce



# Static Magnetic Field

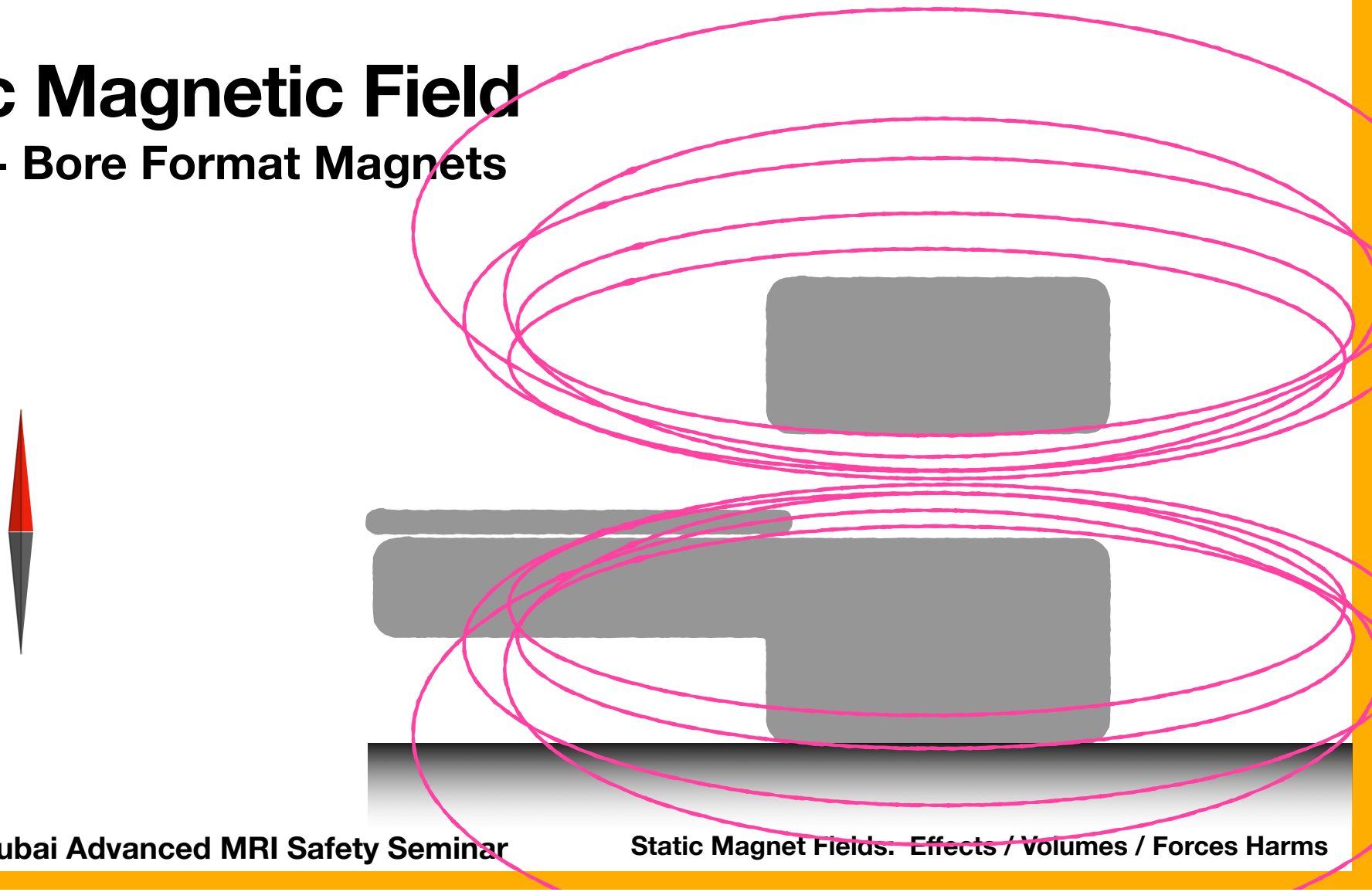
## Torque - Orientation to Mag Field

- The Iron Filings In This Photo Show Us The Lines of Force



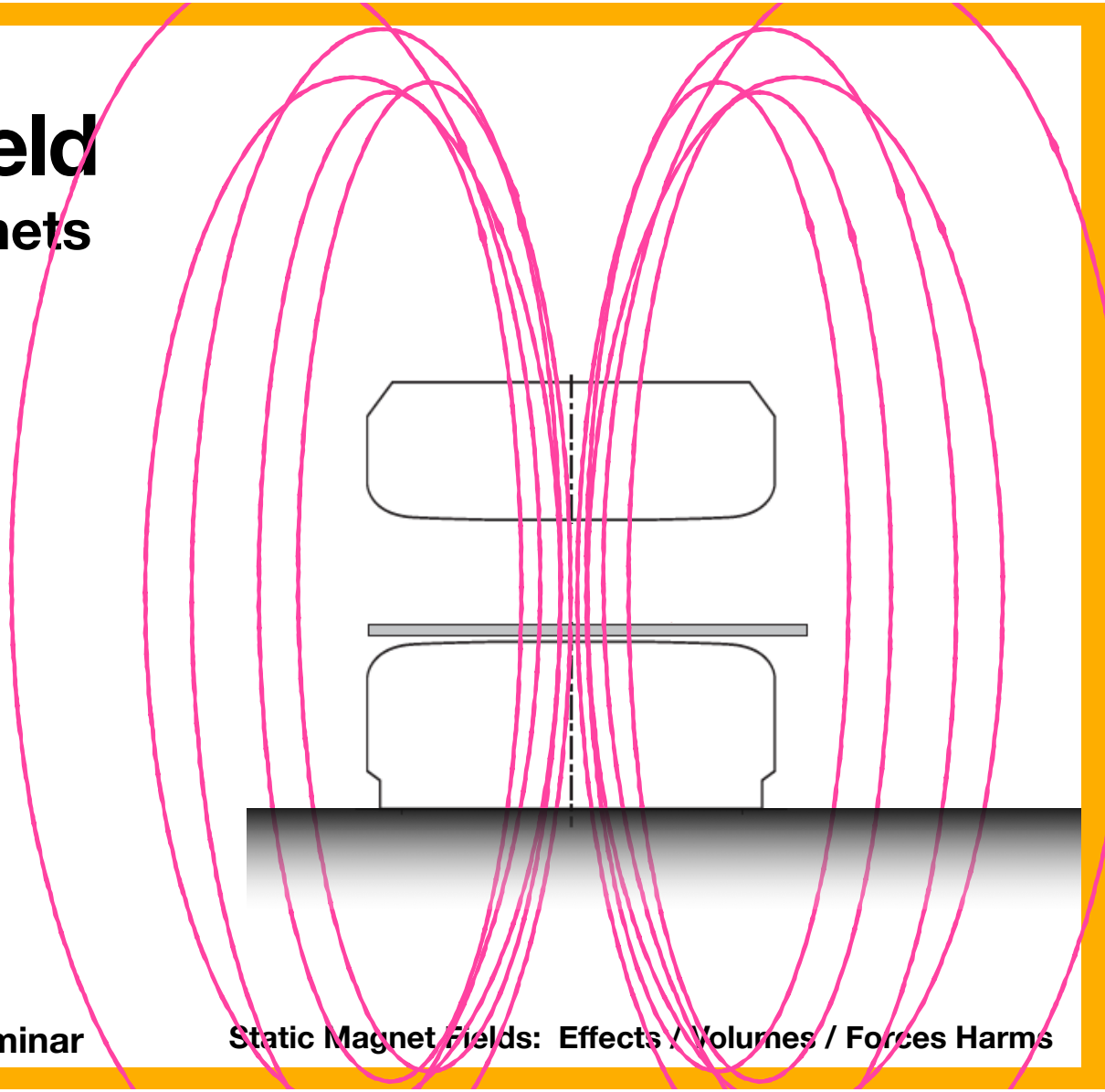

# Static Magnetic Field

## Torque - Bore Format Magnets



# Static Magnetic Field

## Torque - Vertical Field Magnets



# Static Magnetic Field

## Torque - Can You Multiply By Zero?

How Magnetic? **X** How Elongated? **X** Field Exposed?

# Static Magnetic Field

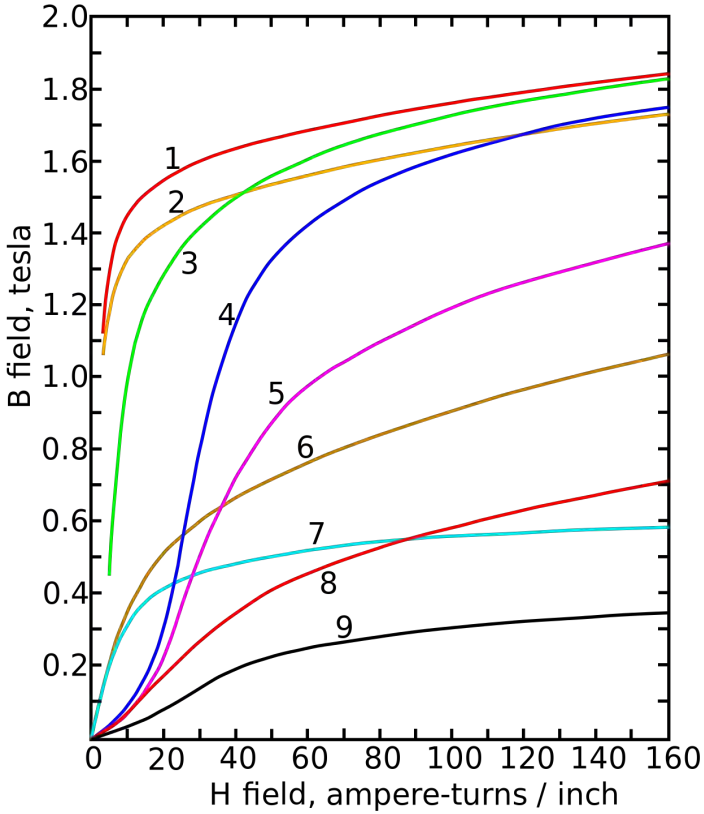
## Translation

- ‘Magnetizability’ of Object
- Length of Object
- Experienced Spatial Field Gradient (SFG)
- Orientation of Object (relative to magnetic field)
- Vertical Field Magnets

# Static Magnetic Field

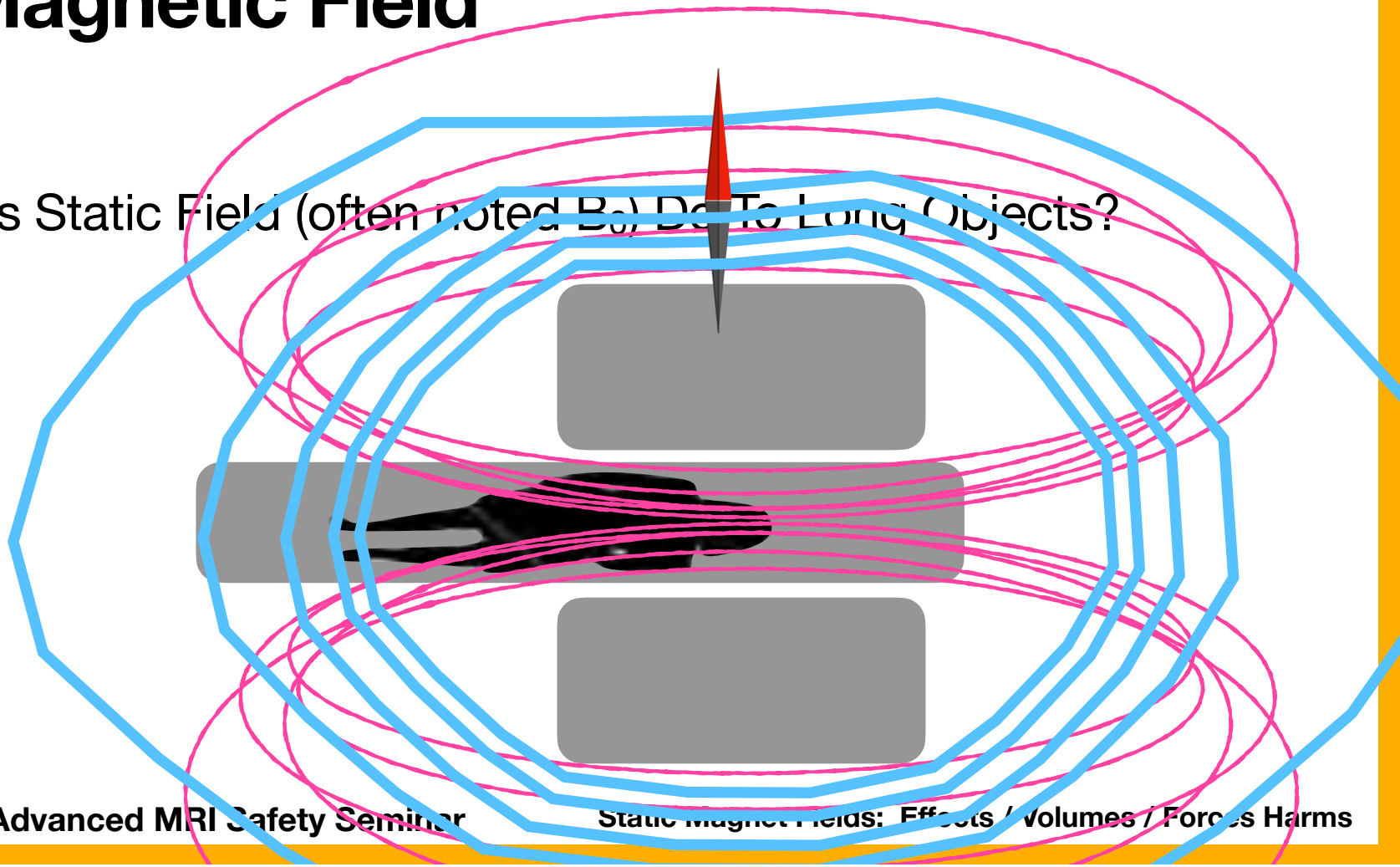
## Translation - Magnetizability

- Magnetic Saturation
- For Many Steel Materials, Saturation Achieved Very Quickly
- Once Saturation Achieved, Spatial Field Gradient (SFG) Main Driver of Translation.

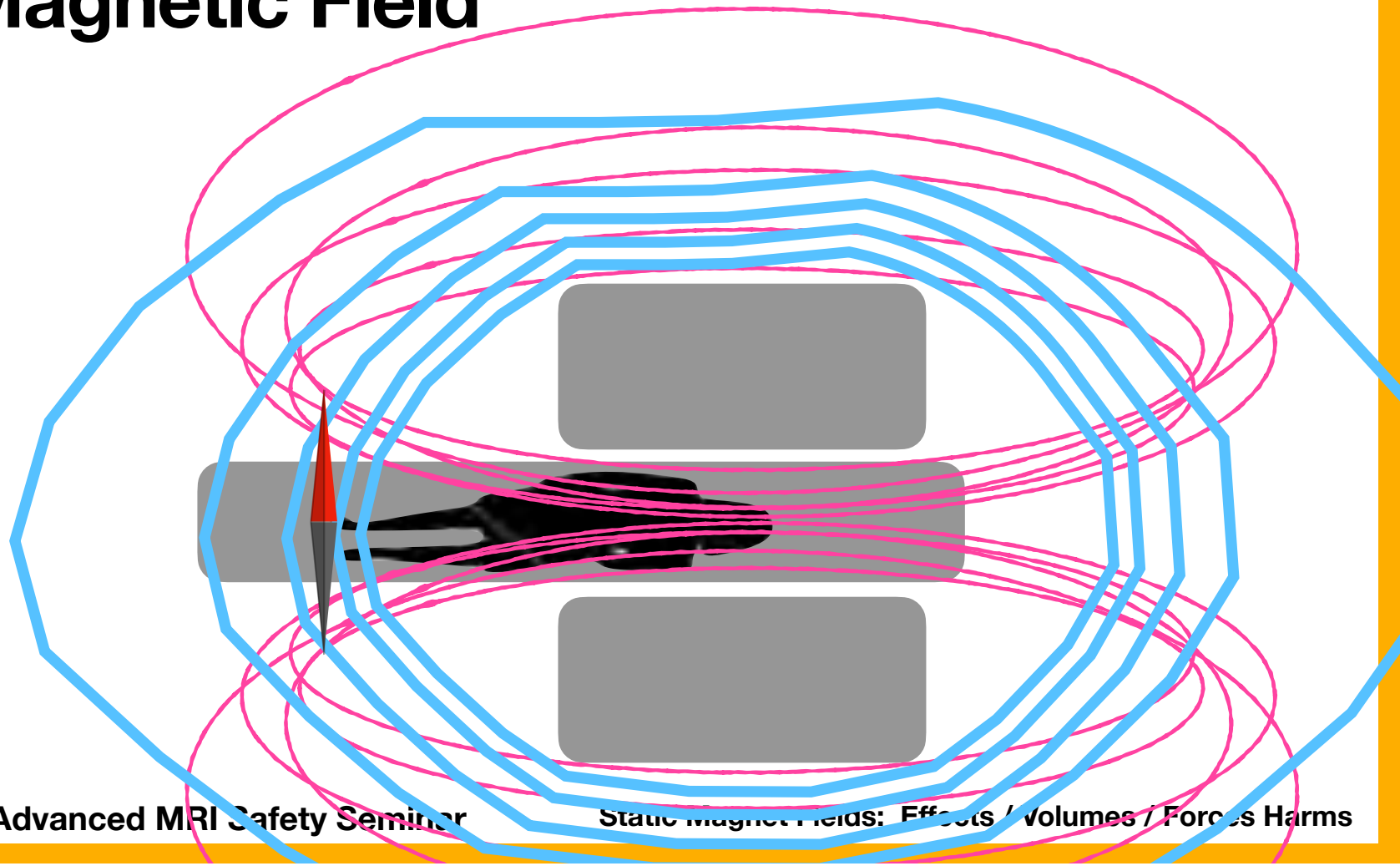


# Static Magnetic Field

- What Does Static Field (often noted $B_0$) Do To Long Objects?



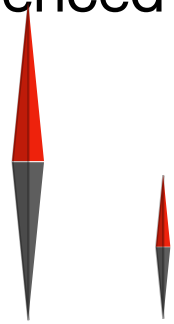
# Static Magnetic Field

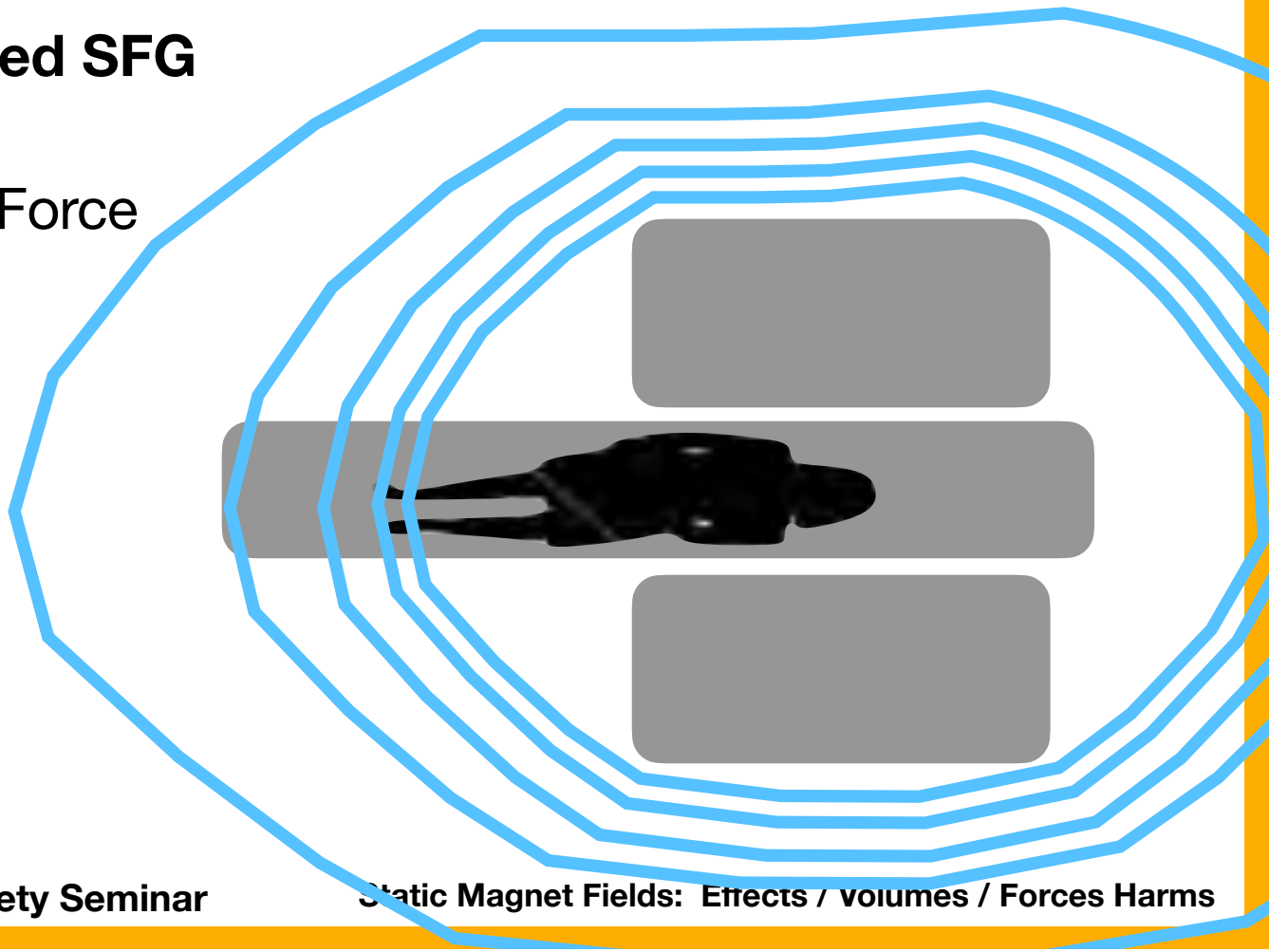


# Static Magnetic Field

## Translation - Experienced SFG

- Translation (Attractive) Force Primarily Driven By Experienced SFG

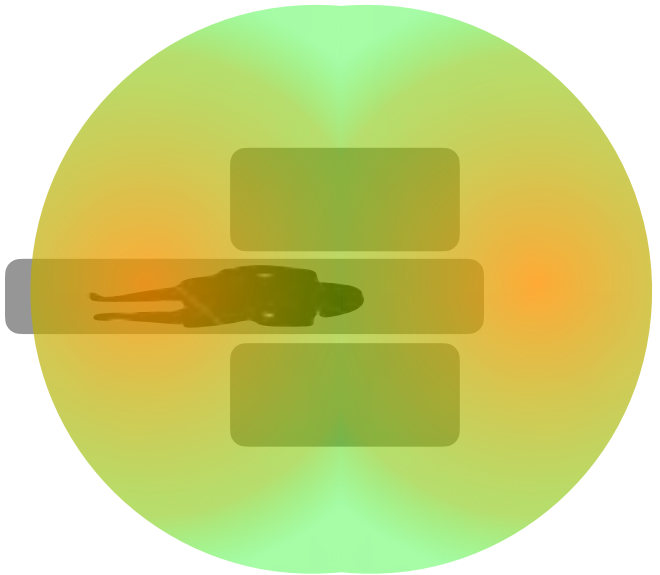




# Static Magnetic Field

## Translation - Orientation (Bore Format Magnets)

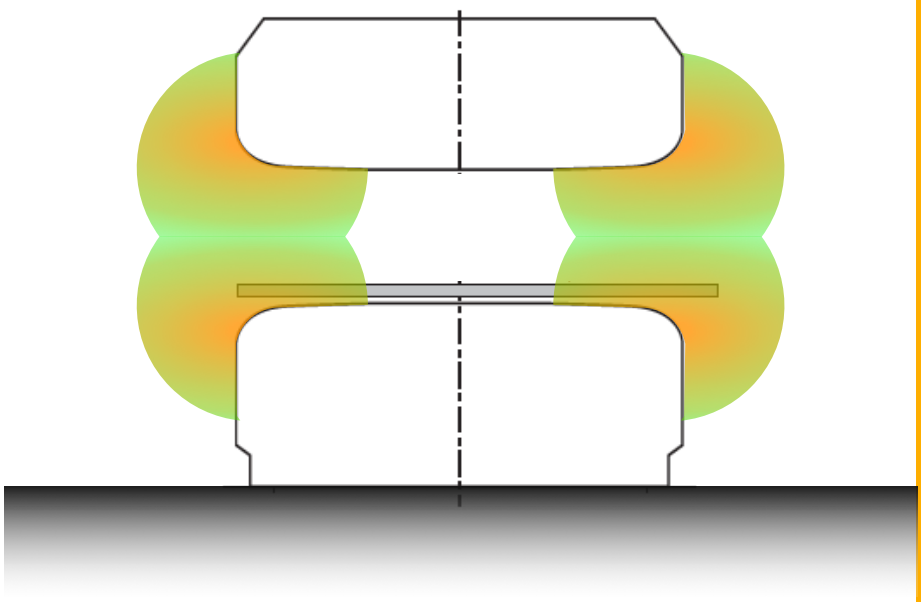
- The More Gauss Lines An Object Crosses, The More Powerful The Attractive Force
- Torque Works To Create Maximum Translational Force Near Mouths Of Magnet
- Torque Works To Create Less Translational Force Along Sides Of Magnet



# Static Magnetic Field

## Translation - Vertical Field Magnets

- Vertical Field (HFO) Magnets' Attractive Forces Increase More Quickly Near Perimeter Of Magnets (Top & Bottom)



# Static Magnetic Field

## Translation - Can You Multiply By Zero?

How Magnetic? **X** Mass of Object? **X** Length of Object? **X** SFG Experienced?

# Static Magnetic Field

## Lenz

- Electrical Conductivity of Object
- Size of Object
- Rate of Motion
- Spatial Field Gradient

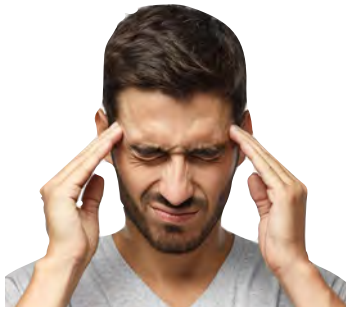
# Static Magnetic Field

## Lenz - Example

https://twitter.com/gunsnrosesgirl3/status/1542481509092933632

# Static Magnetic Field

## Lenz - Faraday's Law



- An Electrical Conductor Experiencing a Changing Magnetic Field Will Generate an Electric Voltage

- A Changing Electrical Current Will Generate a Magnetic Field

# Static Magnetic Field

## Lenz - Electrical Conductivity

- Unlike Torque & Translation, Lenz's Forces Don't Need Magnetizable Materials.
- Electrical Conductivity Is The Key Ingredient
- Electrically Conductive Materials Include Titanium, Stainless Steel, Gold
- The Better Electrical Conductor, The ⤴️ Potential Lenz's Forces

# Static Magnetic Field

## Lenz - Size of Object

- To ⤴️ Lenz's Forces, Make The Object Bigger
- To ⤵️ Lenz's Forces, Make The Object Smaller

# Static Magnetic Field

## Lenz - Rate of Motion

- To ⤴️ Lenz's Forces, Move The Object Faster
- To ⤵️ Lenz's Forces, Move The Object Slower

# Static Magnetic Field

## Lenz - Spatial Field Gradient

- To ⤴️ Lenz's Forces, Move The Object Through Greater SFG
- To ⤵️ Lenz's Forces, Move The Object Through Smaller SFG

# Static Magnetic Field

## Lenz Force - Can You Multiply By Zero?

Electrical Conductivity? **X** Size of Object? **X** Rate of Motion? **X** SFG Experienced?

# Static Magnetic Field

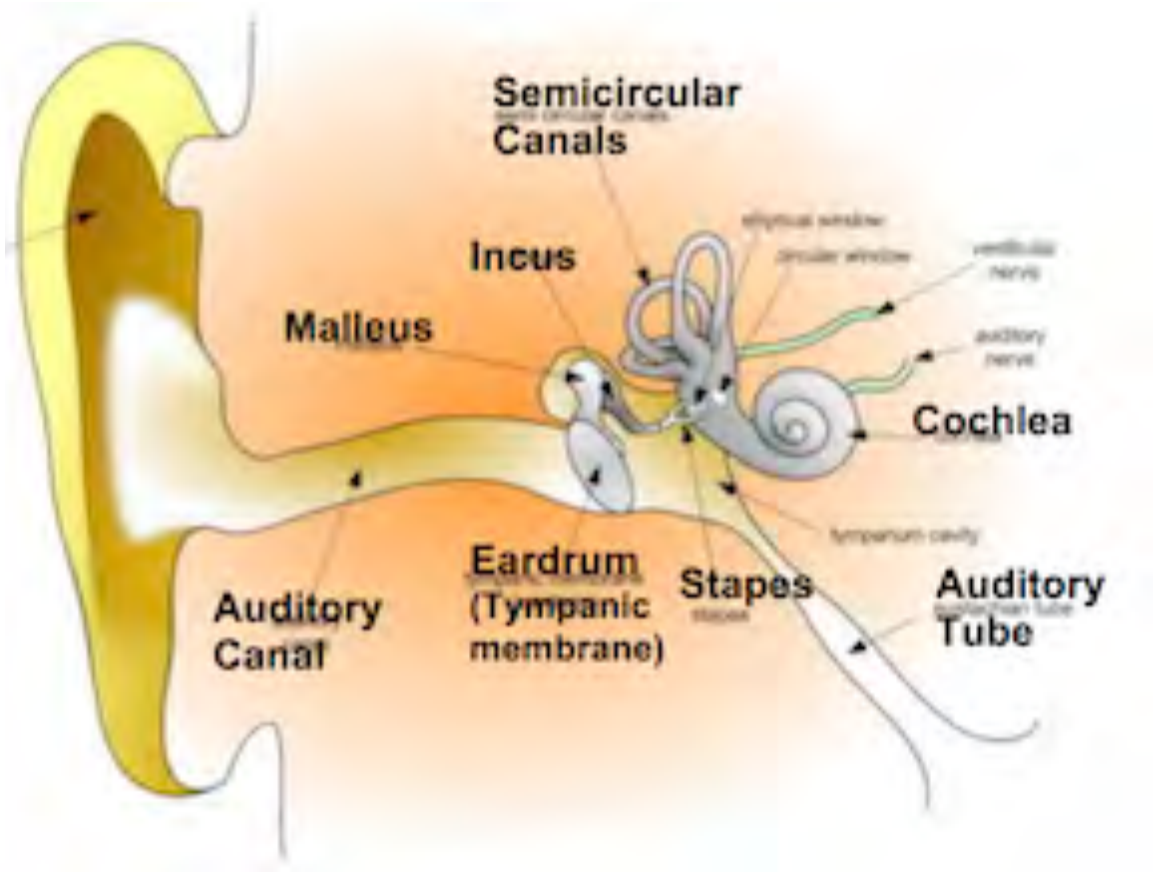
## Physiological Effects

- Inner-Ear Effects (vertigo, nystagmus)
- Flow Potential (ECG interference, S-T segment elevation)
- Magneto Hydrodynamic Effect (MHD)

# Static Magnetic Field

## Inner-Ear Effects

- Ionic Fluid In Cochlea



# Static Magnetic Field

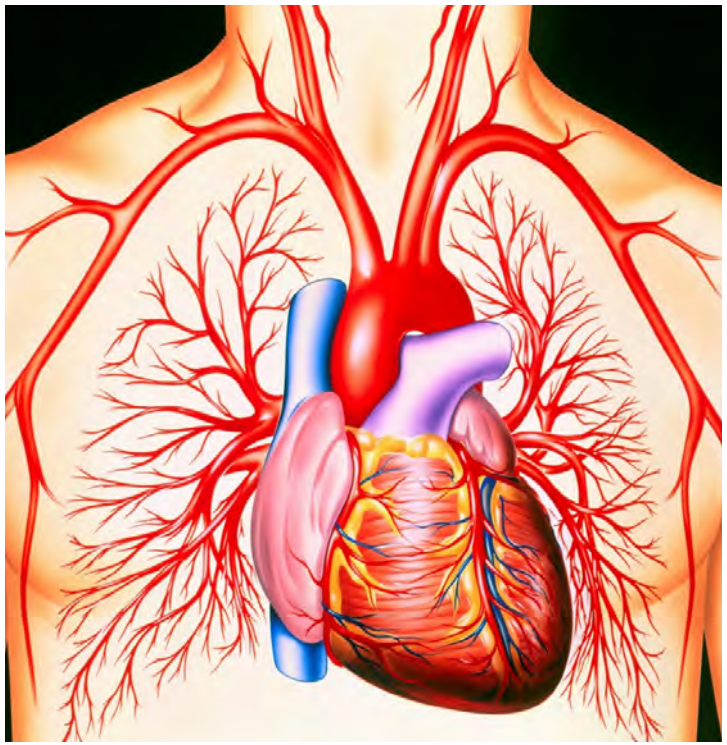
## Flow Potential (ECG Disruption)

- Bloody Faraday's Law
- Blood Is Charged (Electrically Conductive)
- Conductor Moving Through Magnetic Field?
- EKG is a Volt Meter
- Electrical Systole
- Elevated S-T Segment

# Static Magnetic Field

## Magneto Hydrodynamic Effect

- Bloody Lenz's Force
- Blood Is Charged (Electrically Conductive)
- Conductor Moving Through Magnetic Field?
- What Does A Changing Electrical Current Generate?
- 3mm - 5mm Of Additional Mercury Column



# Static Magnetic Field

## Ferromagnetic Detection

# Static Magnetic Field

## Ferromagnetic Detection

# Static Magnetic Field

## Ferromagnetic Detection

- Slightly Misnamed Technology —> Actually Magnetic Field Detectors
- Detect Changing Magnetic Fields Around Them
  - Fields Originating From Magnetizable Objects

# Static Magnetic Field

## Ferromagnetic Detection

- Sensitivity Region
  - Exclude Sources of Interference (You, Step Back)
  - Include Subject Being Screened (Get Them Close)
- Potentials For Environmental Triggers

# Q&A

# Thank You

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