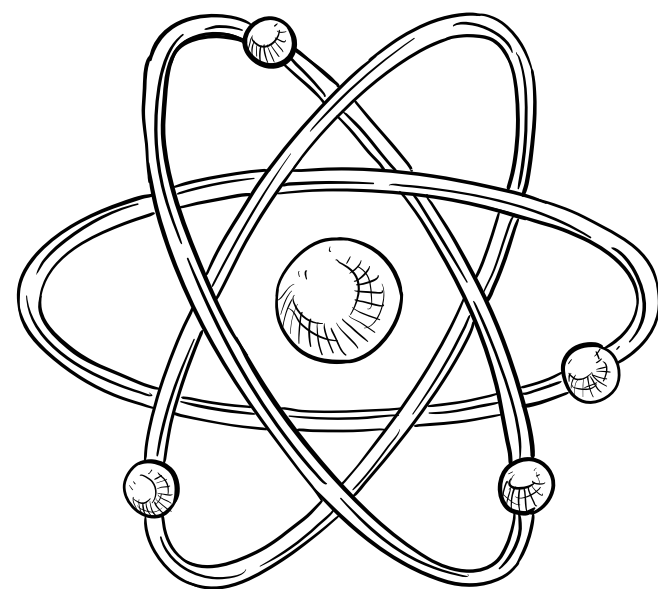
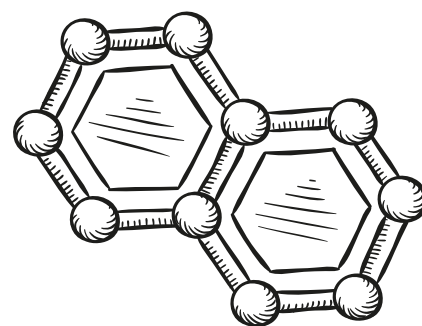
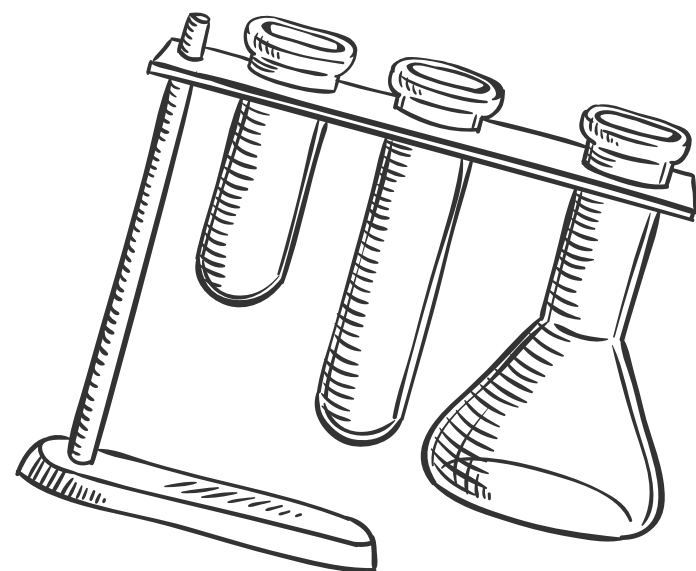
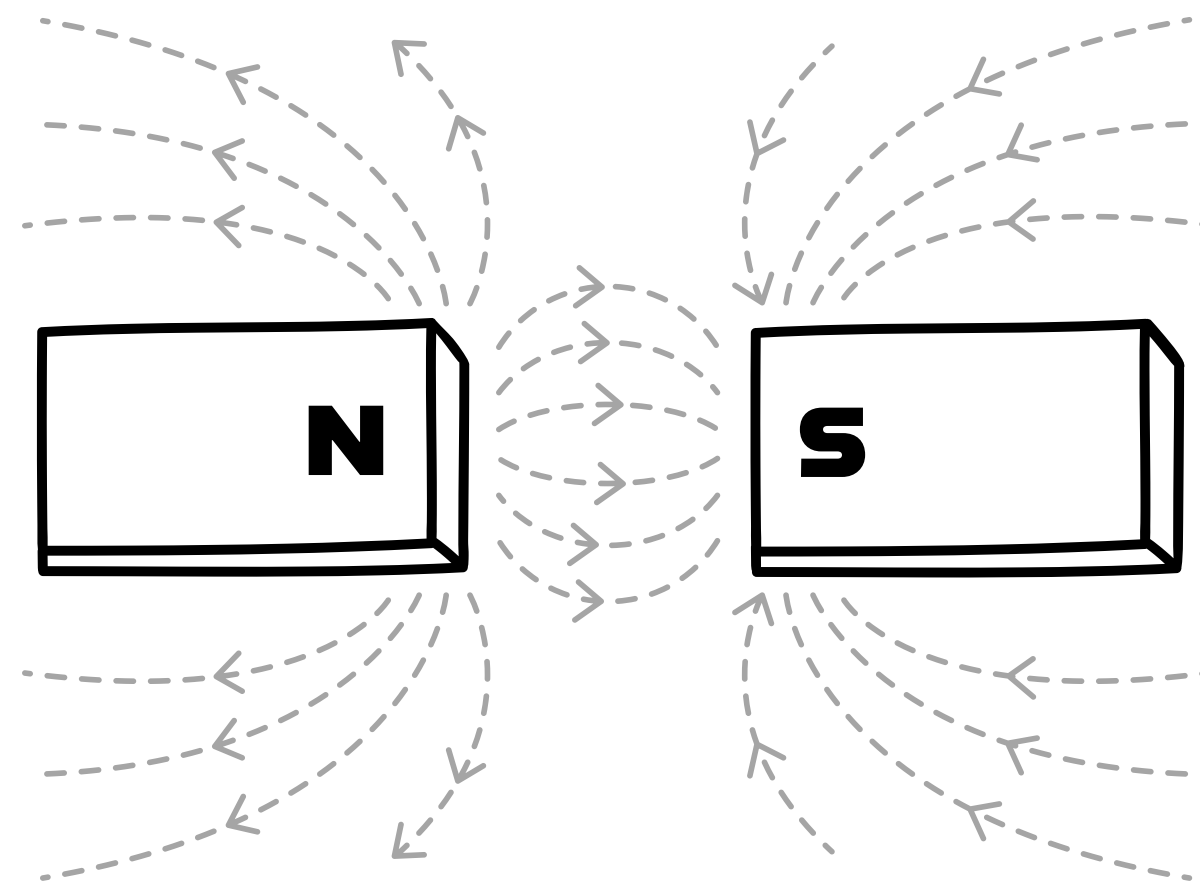
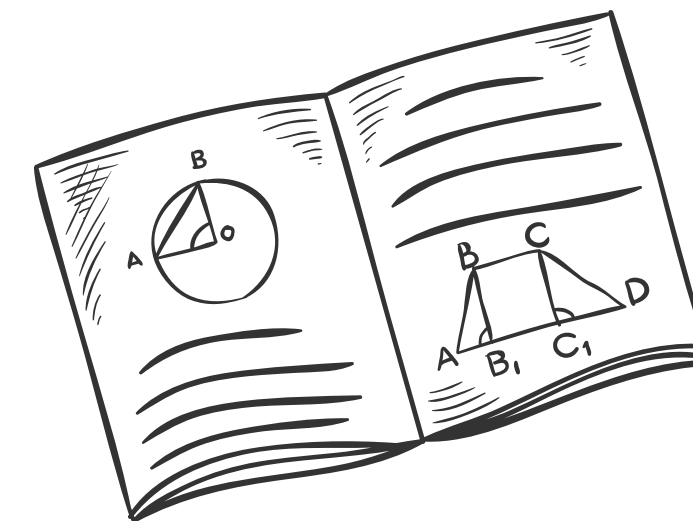
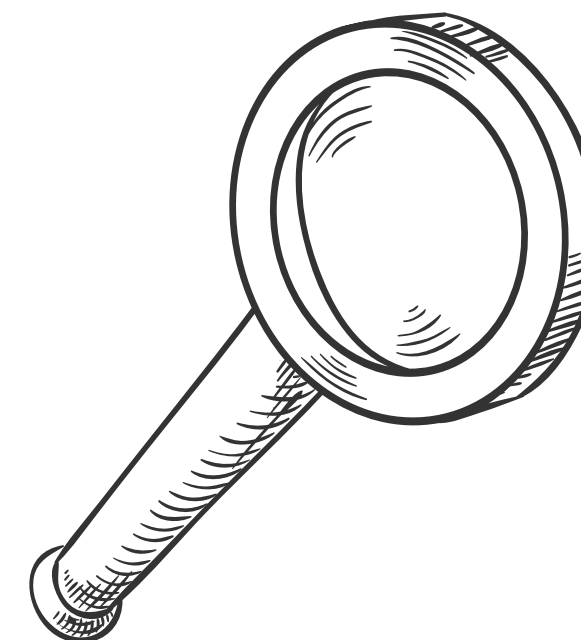


Magnets & the MagLab

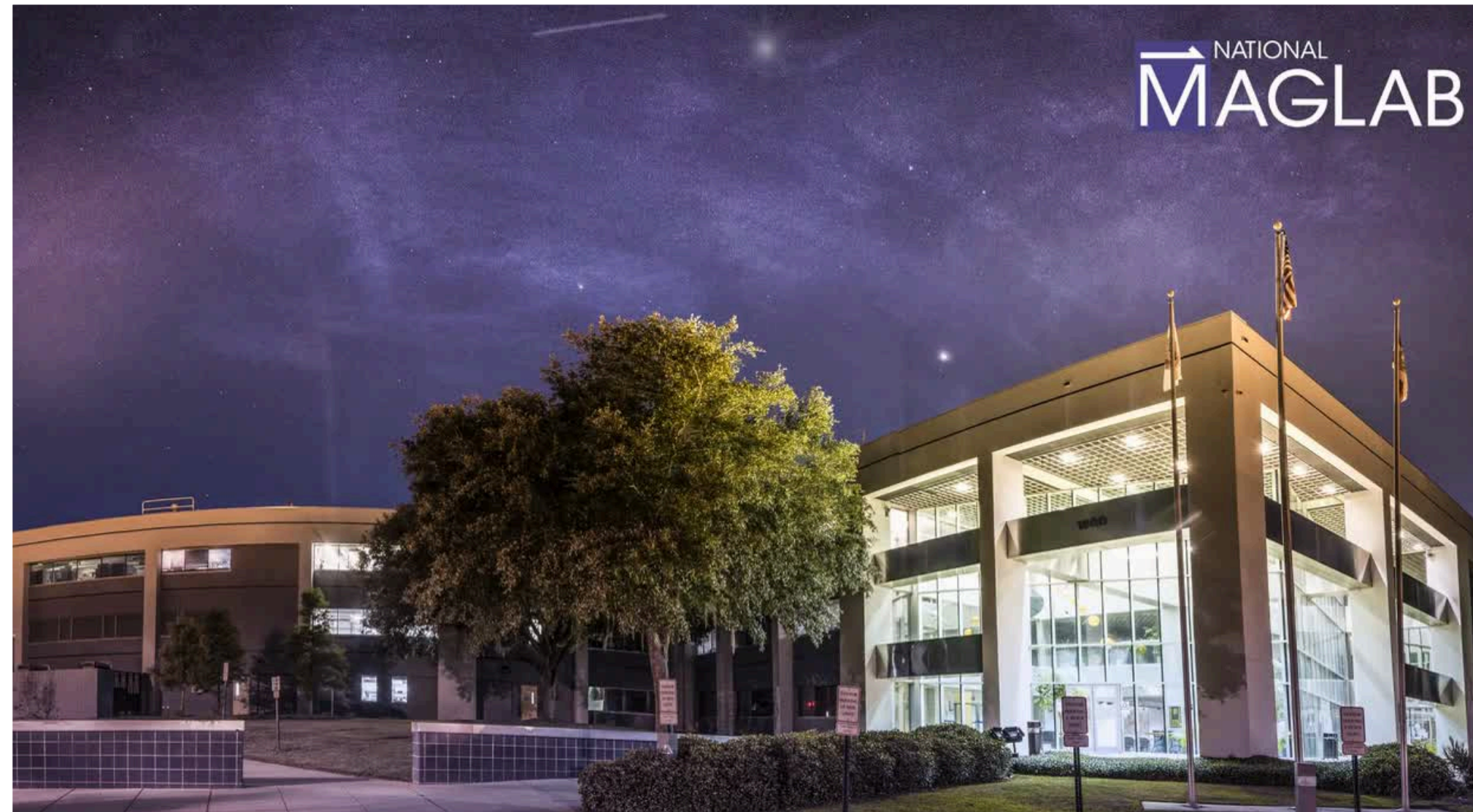
Carlos R. Villa; Director of K-12 Education Programs



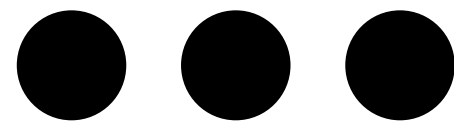


ABOUT THE NATIONAL MAGLAB

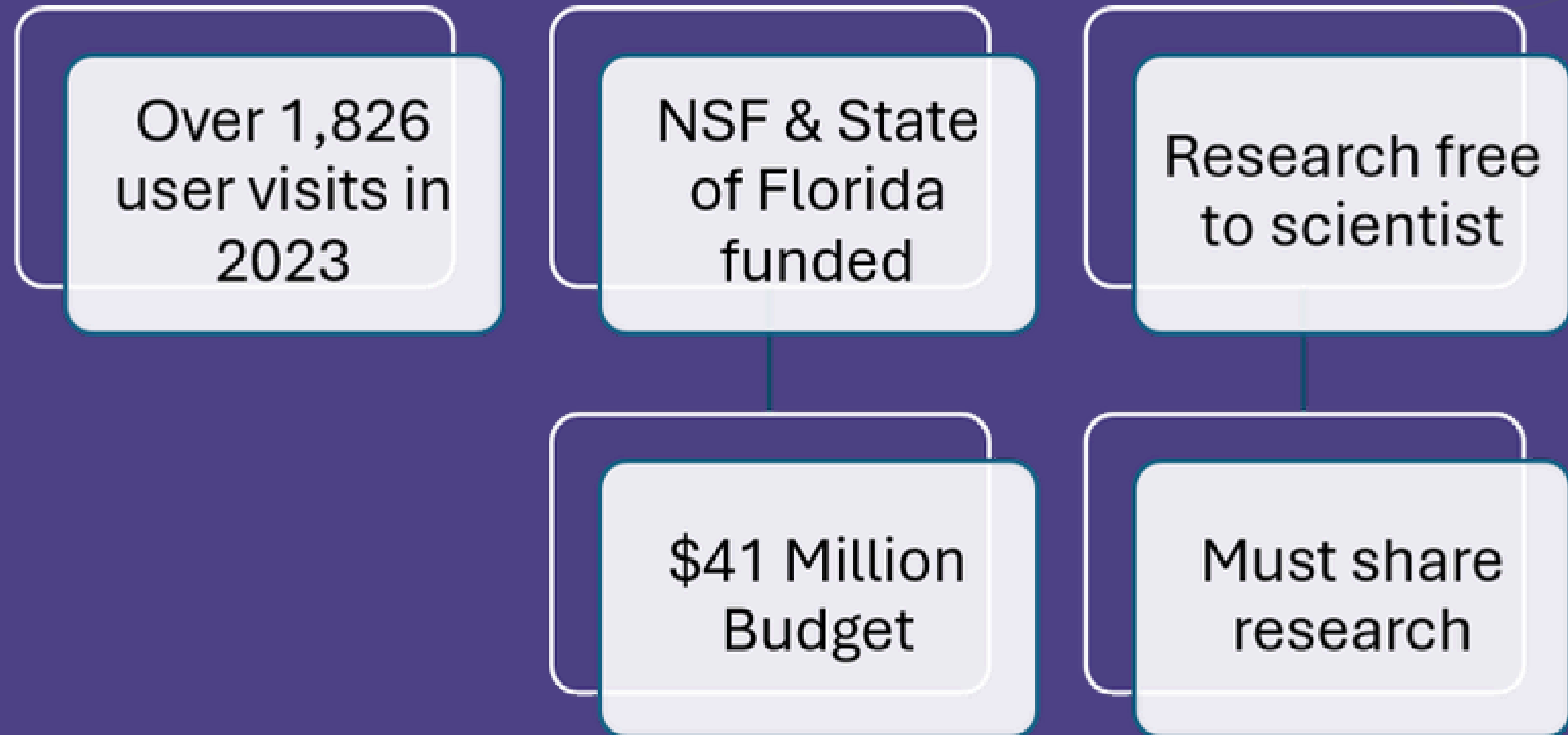
THE NATIONAL MAGLAB



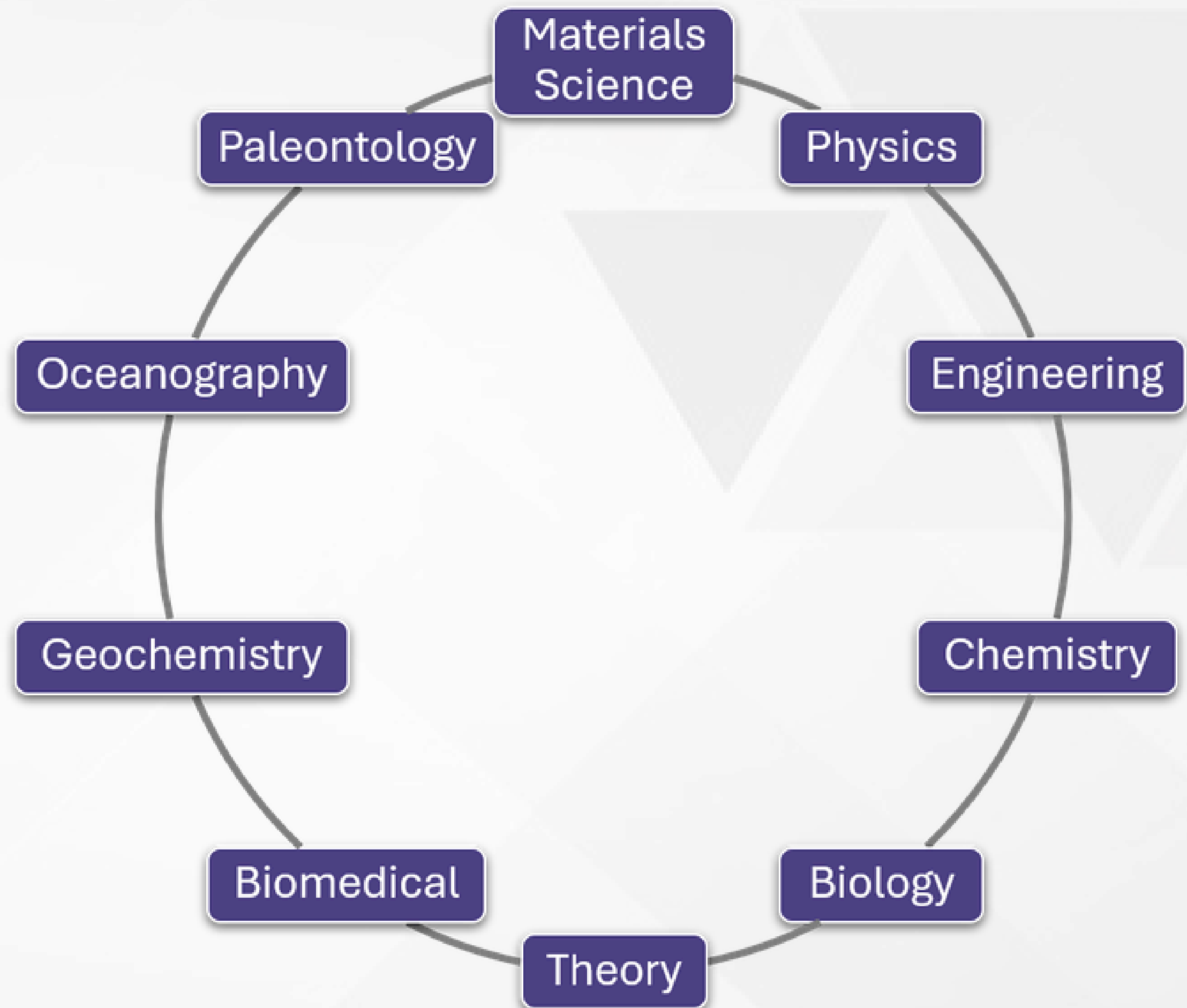
- One of 7 high magnetic field labs in the world
- Only one in western hemisphere
- Largest and highest powered in the world



THE NATIONAL MAGLAB



MAGLAB RESEARCH TOPICS



1 LAB. 3 SITES. 7 USER FACILITIES

AT FLORIDA STATE UNIVERSITY

DC Field: Steady, continuous magnetic fields up to 45 T

Electron Magnetic Resonance (EMR): Magnetic resonance techniques associated with the electron

Nuclear Magnetic Resonance (NMR): Solid & solution state NMR & animal imaging

Ion Cyclotron Resonance (ICR): Ultra-high resolution and high mass accuracy Fourier transform ion cyclotron resonance (FT-ICR) mass spectrometry

LOS ALAMOS NATIONAL LABS

Pulsed Field: Short, ultra-powerful magnetic fields up to 100 T

UNIVERSITY OF FLORIDA

High B/T: Magnetic fields up to 15 T combined with ultra-cold temperatures of 0.4 mK

Advanced Magnetic Resonance Imaging & Spectroscopy (Amris)
High-resolution solution and solid-state, NMR, animal imaging & human imaging



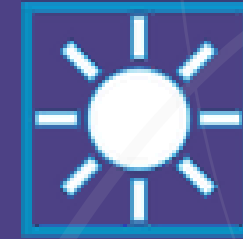
Center for Integrating Research & Learning



Mentoring
& Research



Field Trips
& Tours



Summer
Camps



Professional
development



Workshops
and
Conferences



High
School
Externship



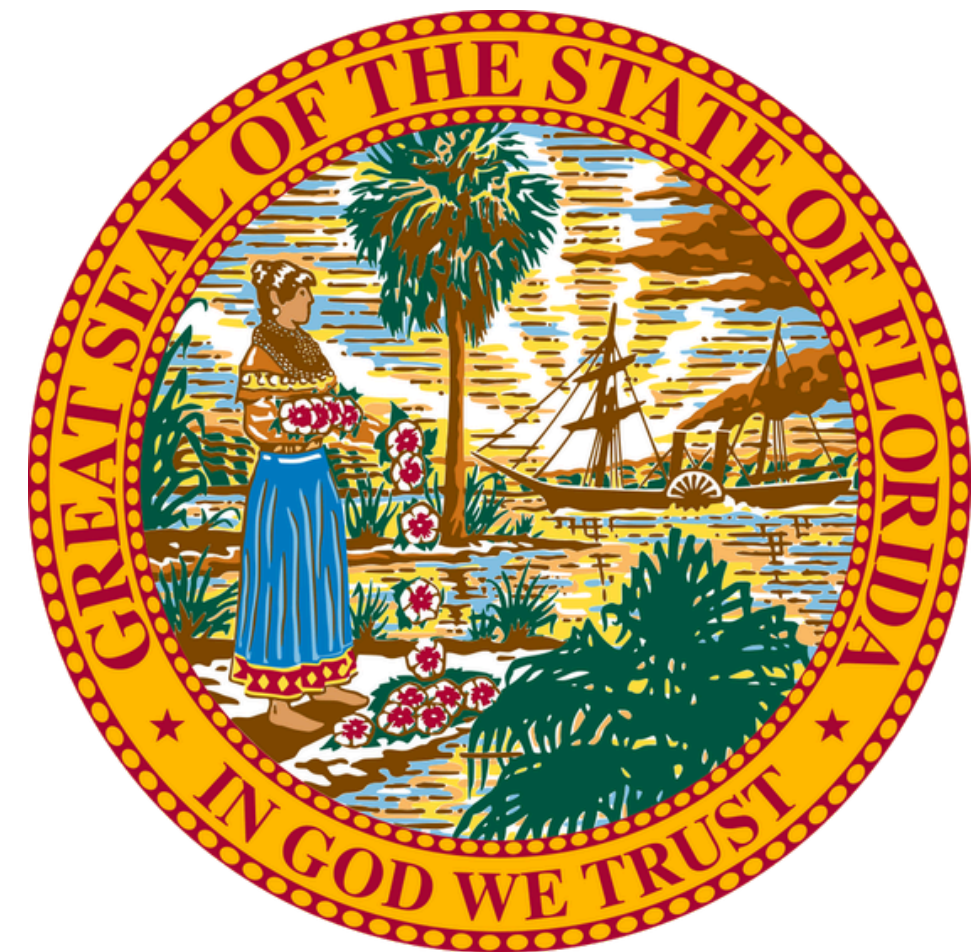
RET
program

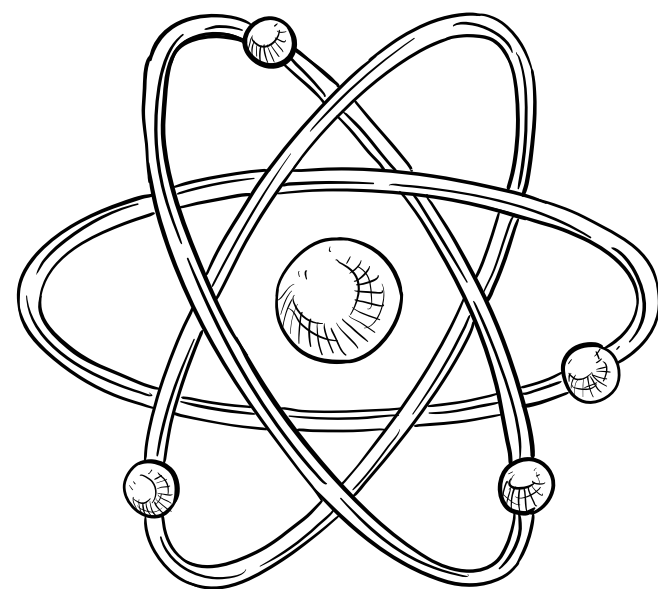
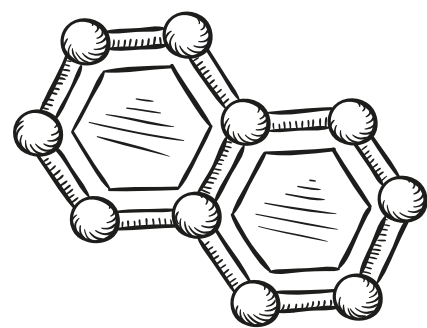
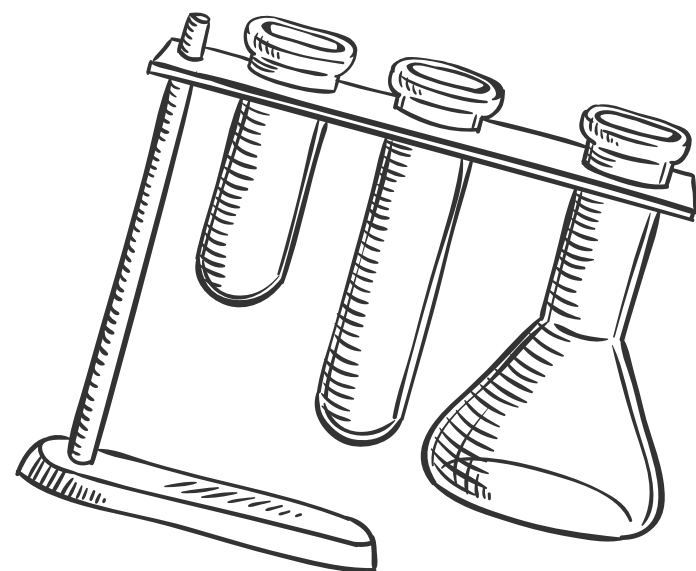
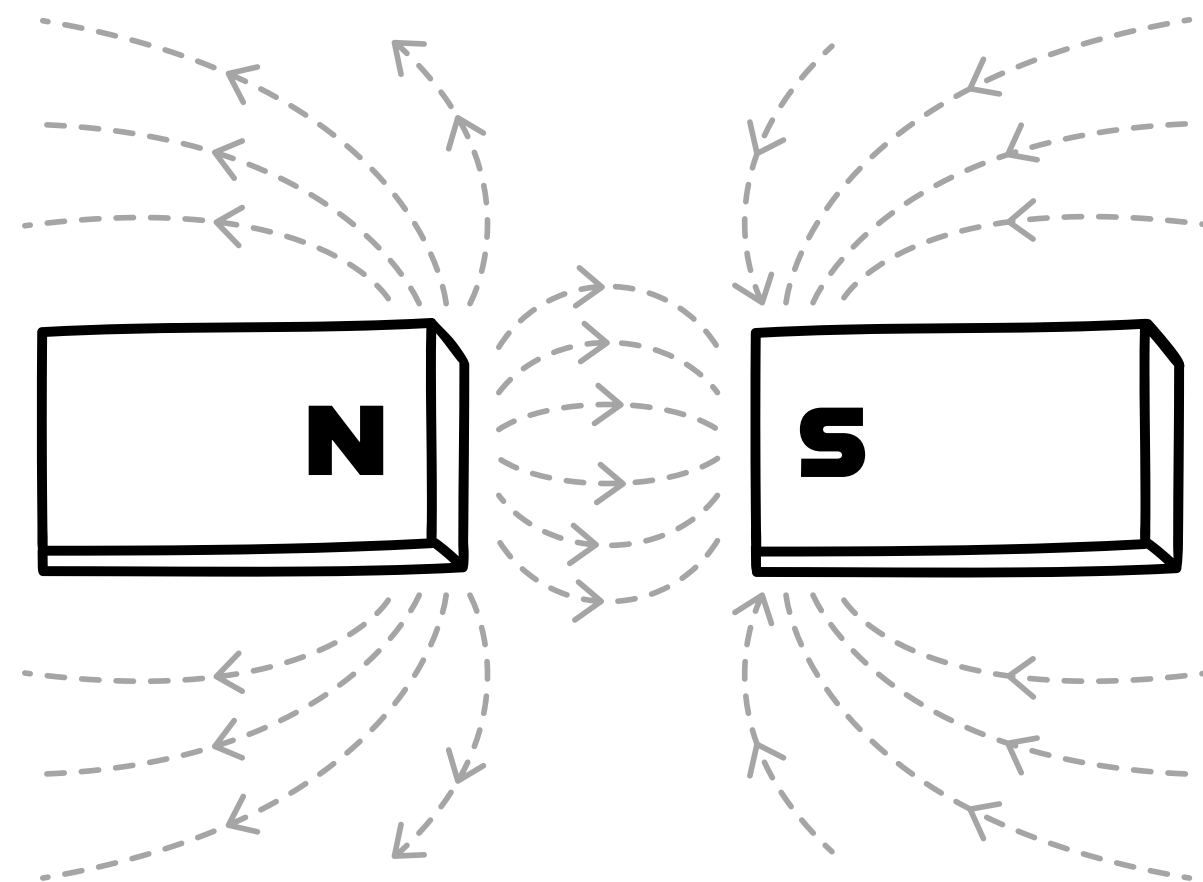
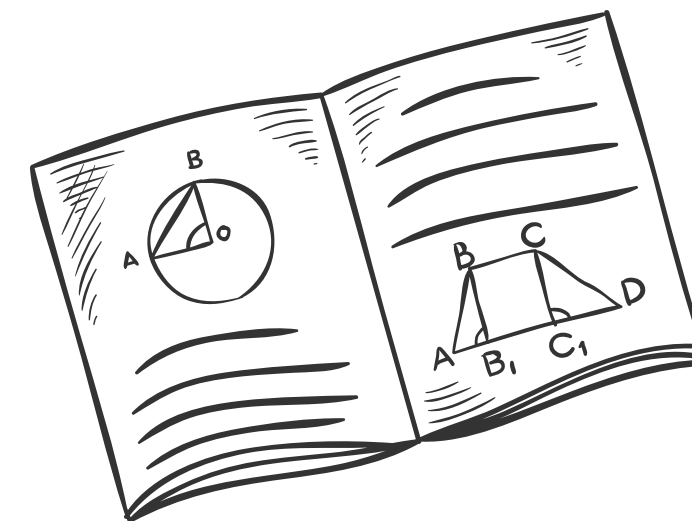
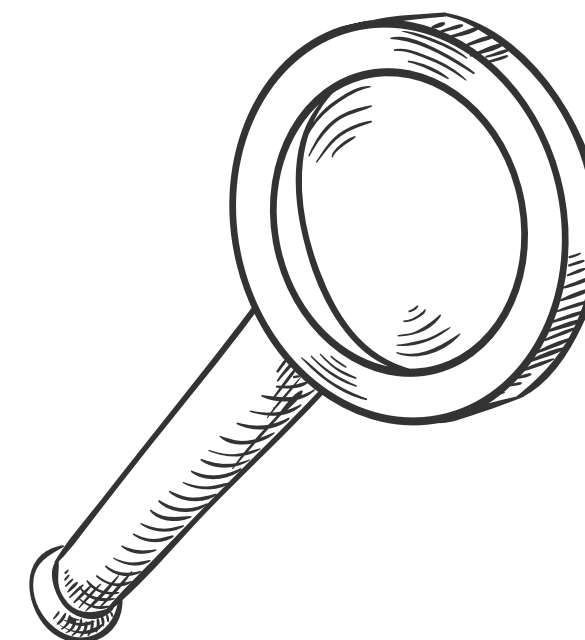
Center for Integrating Research & Learning



**THE NATIONAL MAGLAB IS
TAXPAYER-FUNDED BY THE
NATIONAL SCIENCE FOUNDATION
AND THE STATE OF FLORIDA MAKING
YOU A STAKEHOLDER IN THIS
FACILITY.**

**SO, ON BEHALF OF ALL OF US, THANK
YOU FOR SUPPORTING OUR
SCIENCE.**

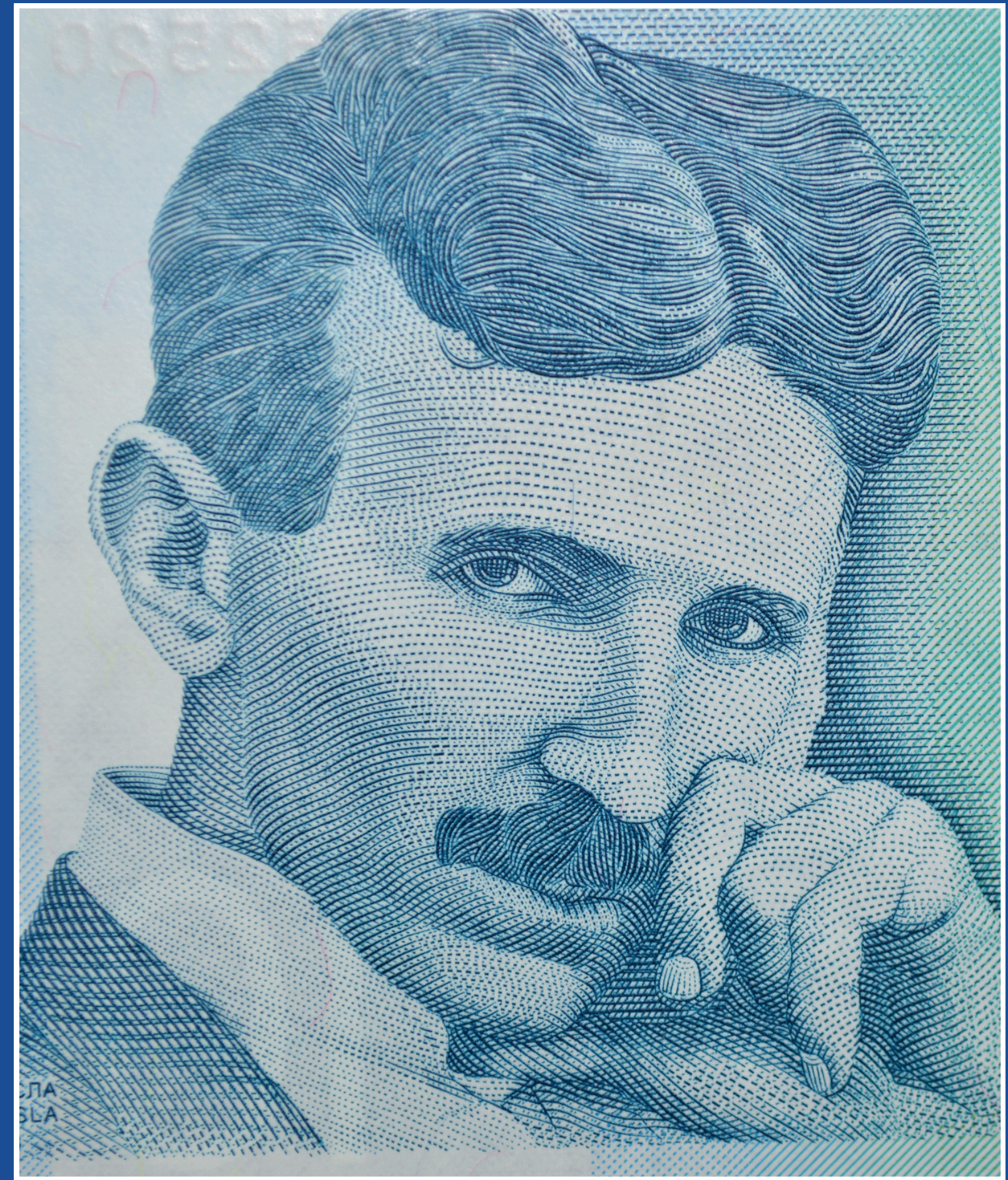




MAGNET SCIENCE

NIKOLA TESLA

- Born During a Storm: born in Smiljan, Austrian Empire (now Croatia), on July 10, 1856. Lightning storm lead midwife to call him a "child of darkness." While his mother countered that he would be a "child of light".
- Alternating Current: allowed electricity to travel over long distances safely; became global standard for power systems.
- Showed Early Wireless Remote Control: showcased world's first remote-controlled boat using radio waves to control its movements.
- Magnetic Fields: Unit for measurement of magnetic fields named for him.



MAGNETIC FIELDS

IN TESLA



MAGNETIC FIELDS

IN TESLA



.03 tesla



MAGNETIC FIELDS

IN TESLA



.03 tesla



.00005 tesla



MAGNETIC FIELDS

IN TESLA



.03 tesla



.00005 tesla



1 tesla



MAGNETIC FIELDS

IN TESLA



.03 tesla



.00005 tesla



1 tesla



2-3 tesla

MAGNETIC FIELDS

IN TESLA

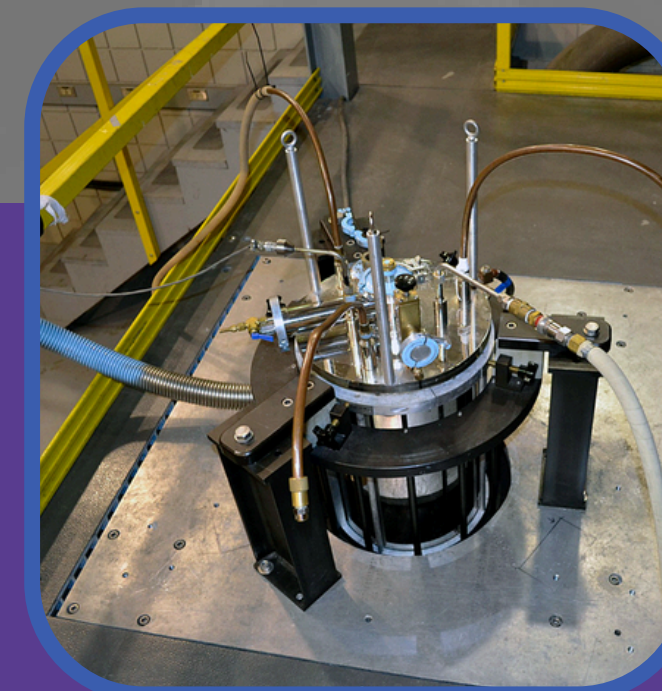


MAGNETIC FIELDS

IN TESLA



**Ion Cyclotron
Resonance
21 tesla**



MAGNETIC FIELDS

IN TESLA



**Ion Cyclotron
Resonance
21 tesla**



**Nuclear Magnetic
Resonance
21 tesla**



MAGNETIC FIELDS

IN TESLA



**Ion Cyclotron
Resonance
21 tesla**



**Nuclear Magnetic
Resonance
21 tesla**



**Split Cell
25 tesla**



MAGNETIC FIELDS

IN TESLA



**Ion Cyclotron
Resonance
21 tesla**



**Nuclear Magnetic
Resonance
21 tesla**



**Split Cell
25 tesla**



**DC Resistive
31 tesla**

MAGNETIC FIELDS

IN TESLA



MAGNETIC FIELDS

IN TESLA



**DC Resistive
41 tesla**

MAGNETIC FIELDS

IN TESLA



**DC Resistive
41 tesla**



**Series
Connected Hybrid
33 tesla (14 MW)**



MAGNETIC FIELDS

IN TESLA



**DC Resistive
41 tesla**



**Series
Connected Hybrid
33 tesla (14 MW)**



**Hybrid
45 tesla
33 MW**



MAGNETIC FIELDS

IN TESLA



**DC Resistive
41 tesla**



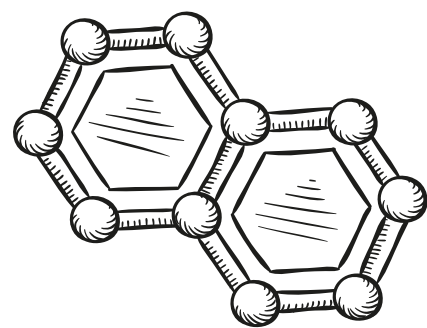
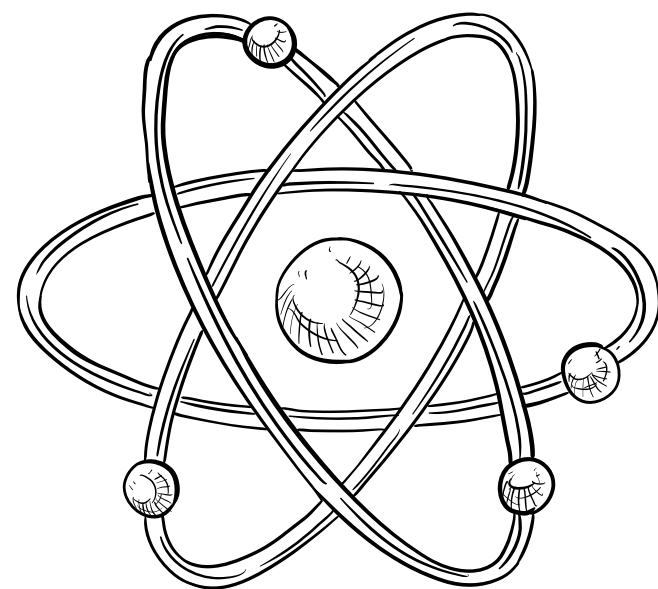
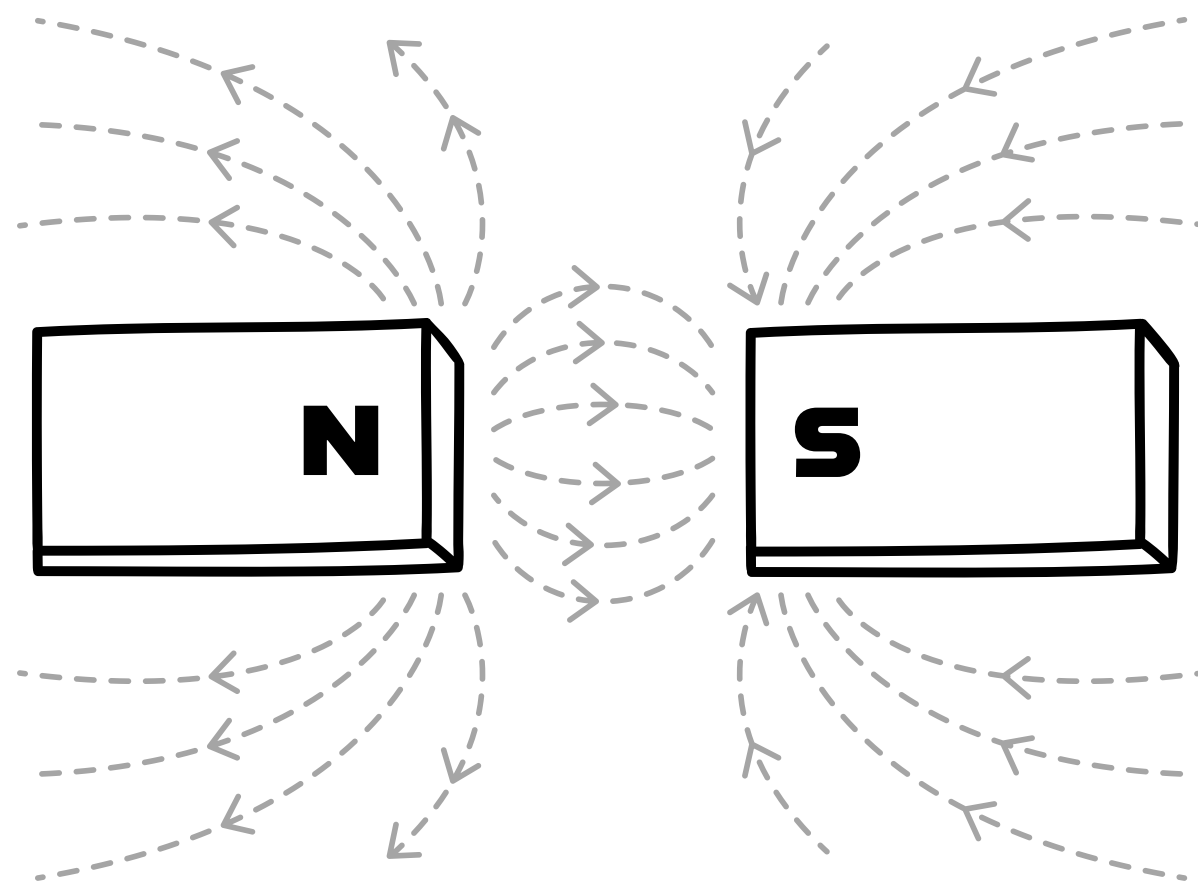
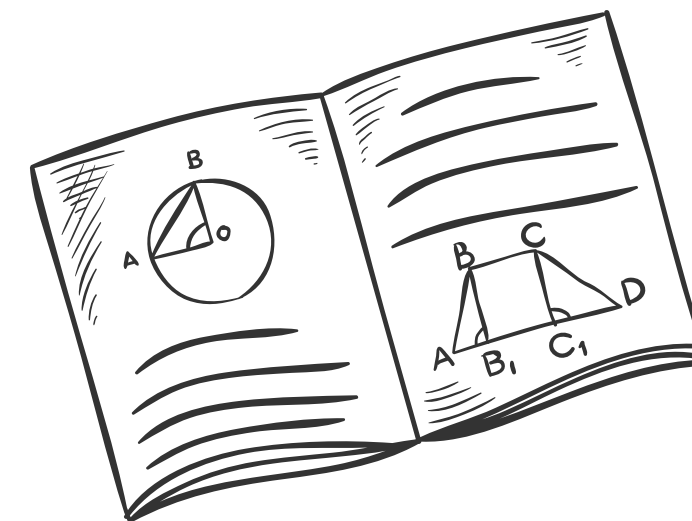
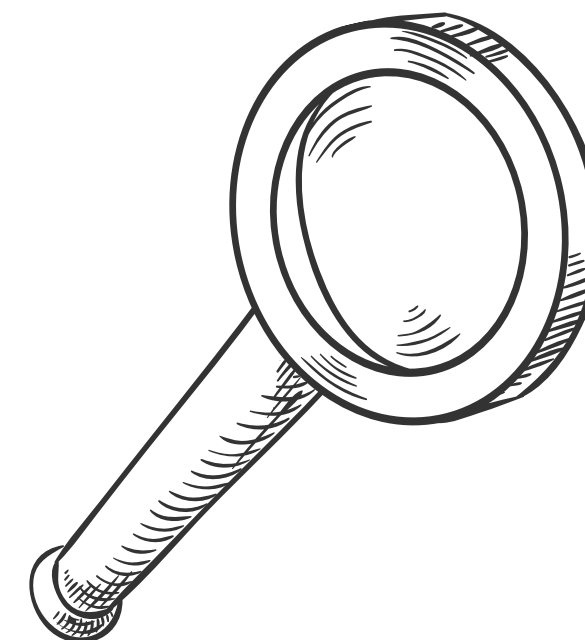
**Series
Connected Hybrid
33 tesla (14 MW)**



**Hybrid
45 tesla
33 MW**

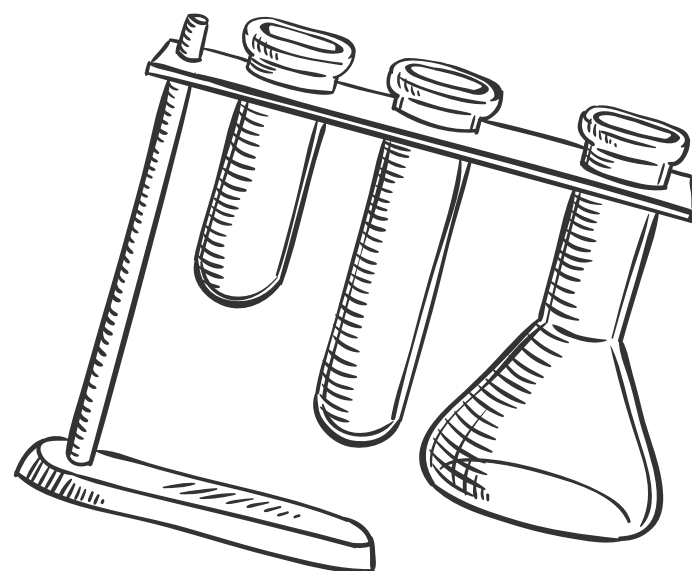


**Pulse Magnet
100 tesla**



MAGNETISM

THROUGH HISTORY





GREECE: 2000 BC

MAGNES THE
SHEPHERD



CHINA: 400 BC

FENG SHUI:
THE SOUTH POINTER



ROME: 50 AD

PLINY THE ELDER:
NATURALIST AND
RESEARCHER
“MAGIC” WITH
HEALING PROPERTIES

1269: Petrus Peregrinus de Maricourt

Epistola de Magnete

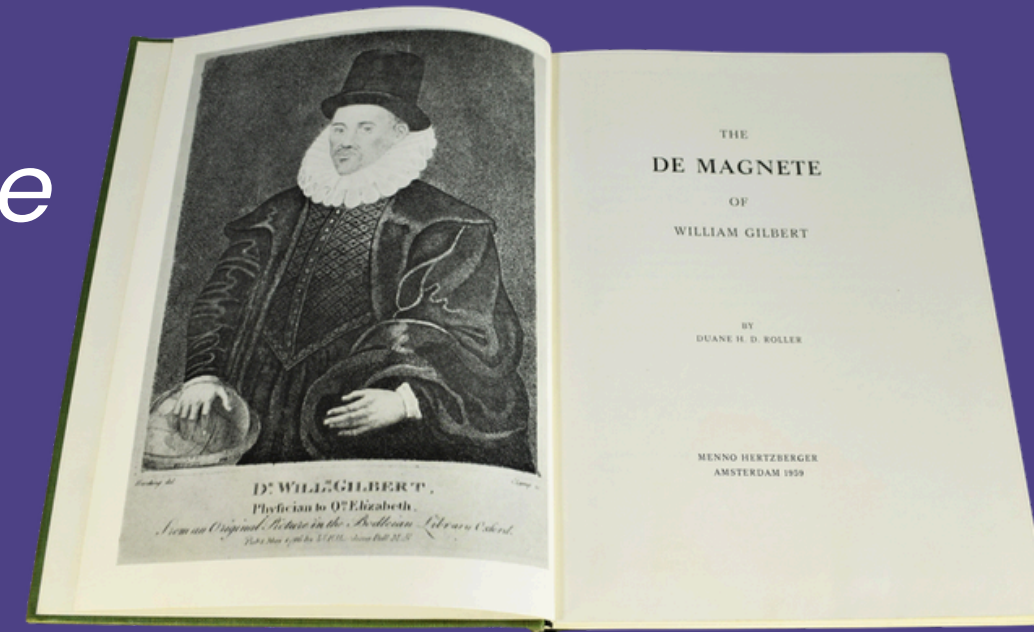
- Part 1 discusses the physical (not occult) properties of magnets
 - Magnetic fields can act at a distance
 - Magnets can only act on other magnetic materials
 - Opposite poles attract and like poles repel
 - When suspended, north poles point North and south poles point South.
- Part 2 discusses the use of magnets in devices
 - Wet and dry compass



1600: WILLIAM GILBERT



- Published *De Magnete*
- First critical research on magnets
- Used lodestone
- Dispelled superstitions and myths
- Declared Earth is a magnet



1820: HANS CHRISTIAN ØRSTED

- An electrical current can create a magnetic field
- Ørsted set up lecture demonstration
 - Used battery to supply current
 - Showed compass needle deflecting near the wire



Electricity and magnetism are not independent phenomenon

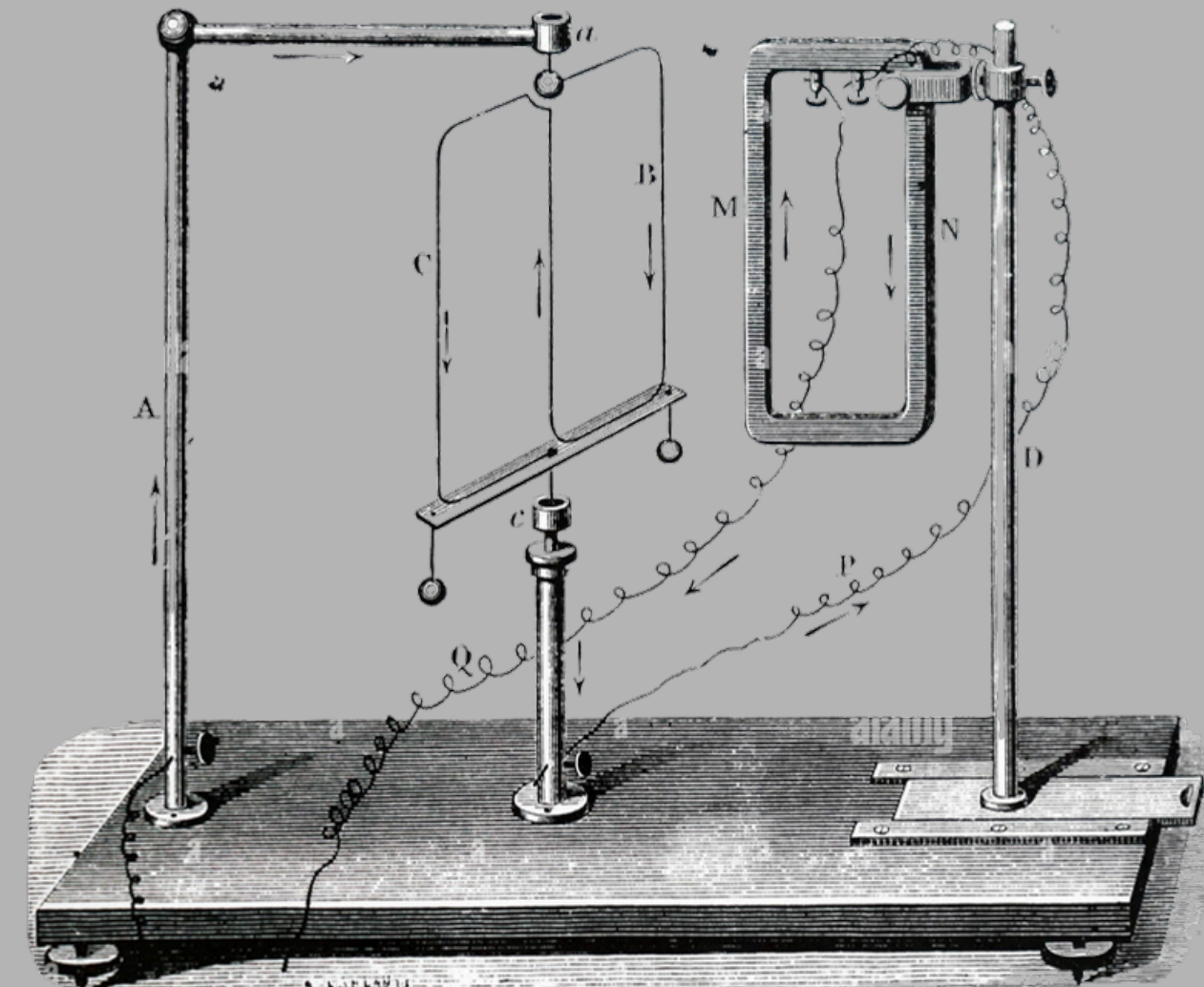
1820

ANDRÉ-MARIE AMPÈRE

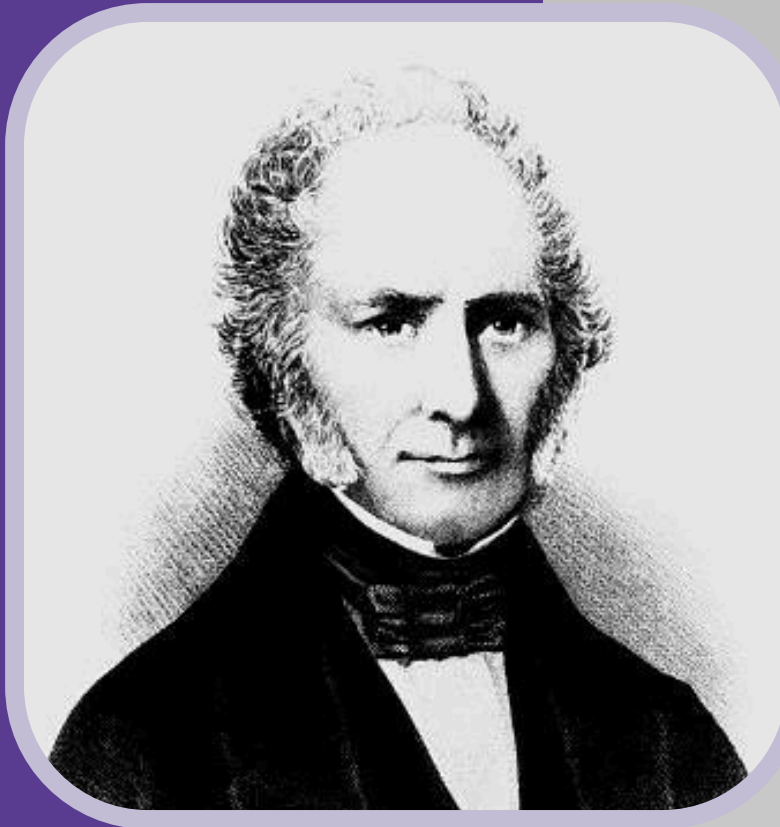
Hypothesis: Moving electrical charges produce magnetic fields

Performed a simple experiment

- Two straight wires with current passed through
- Wires bowed toward or away
- Electric currents exert a magnetic force on each other
- Led to electromagnets



MEET THE ELECTROMAGNET 1824



WILLIAM STURGEON

- English electrical engineer and inventor
- Made the first electromagnet
- Made the first practical electric motor.



FIRST ELECTROMAGNET

- Curved iron rod
- Bare copper wire
- Electricity
- 18 total turns of wire
- Magnet weighed 7 ounces
- Lifted 9 pounds

1827 New Innovative Electromagnet



Joseph Henry

- American physicist and inventor
- Served as first secretary of the Smithsonian Institution
- Served as president of the National Academy of Sciences



New Electromagnet

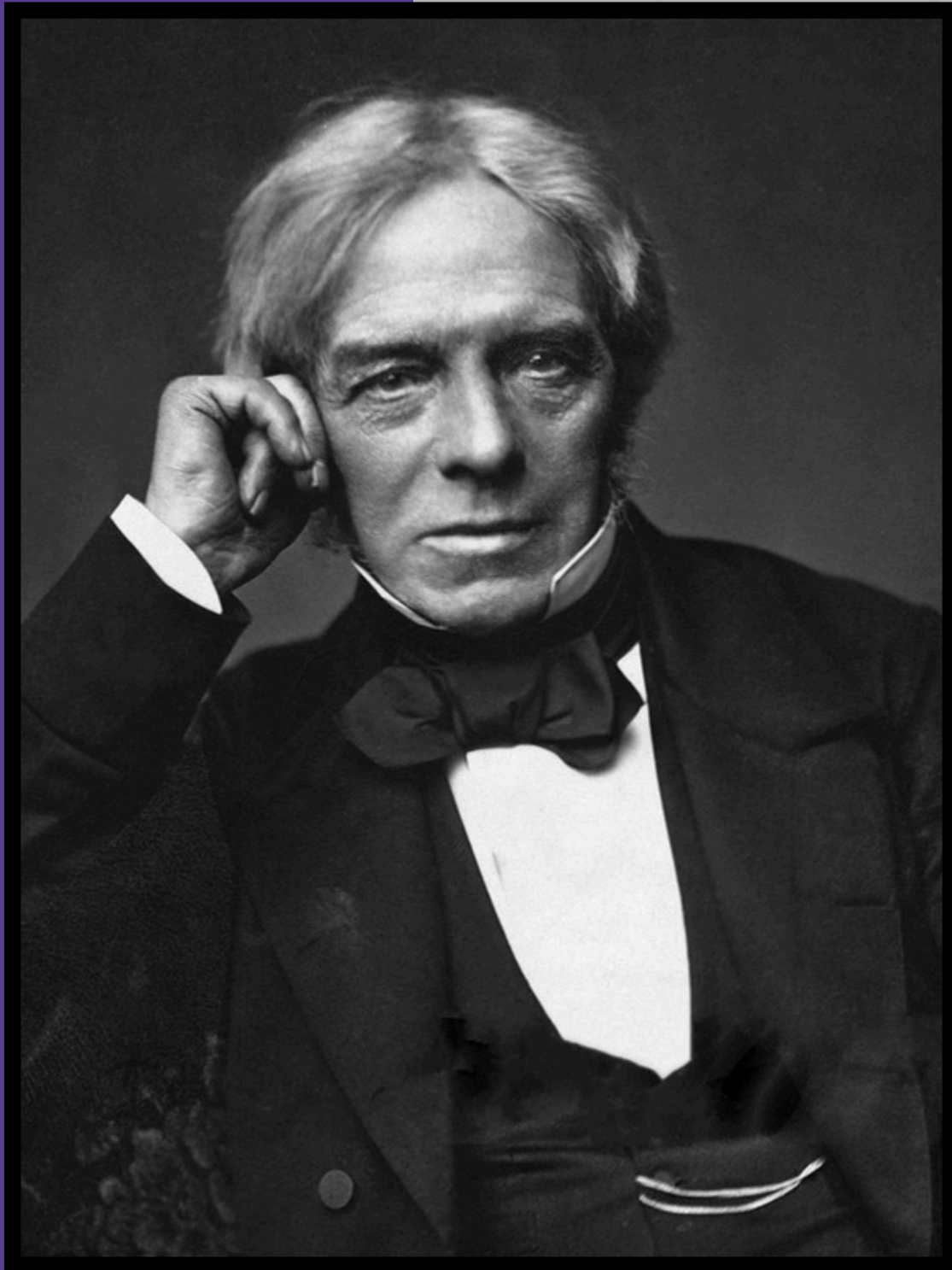
- First to coil insulated wire tightly around an iron core
- Copper wire insulated with silk

When making an electromagnet using a battery: it is best to wind several coils of wire in parallel.

When using multiple batteries: there should be only one single long coil.

1831

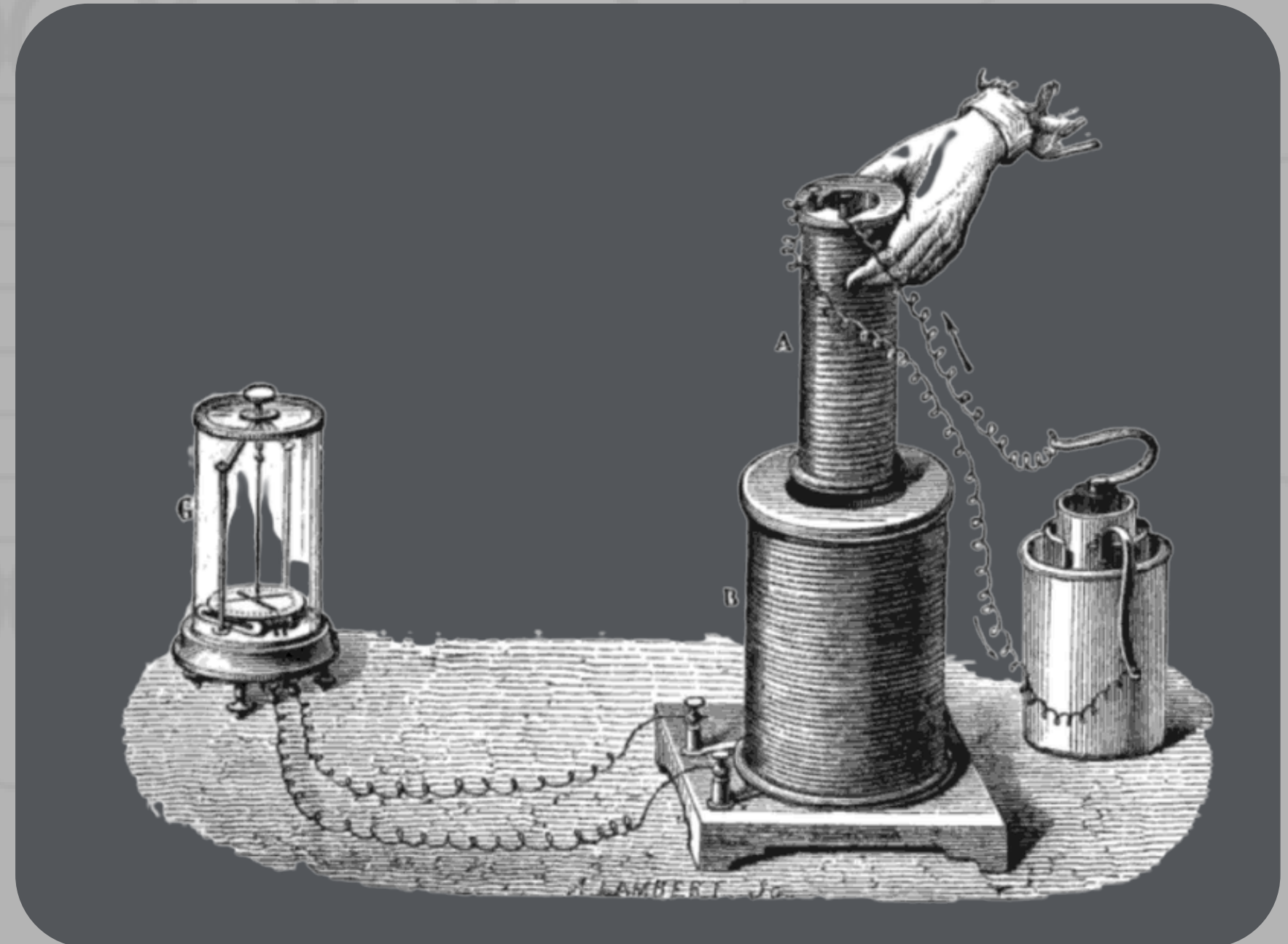
MICHAEL FARADAY



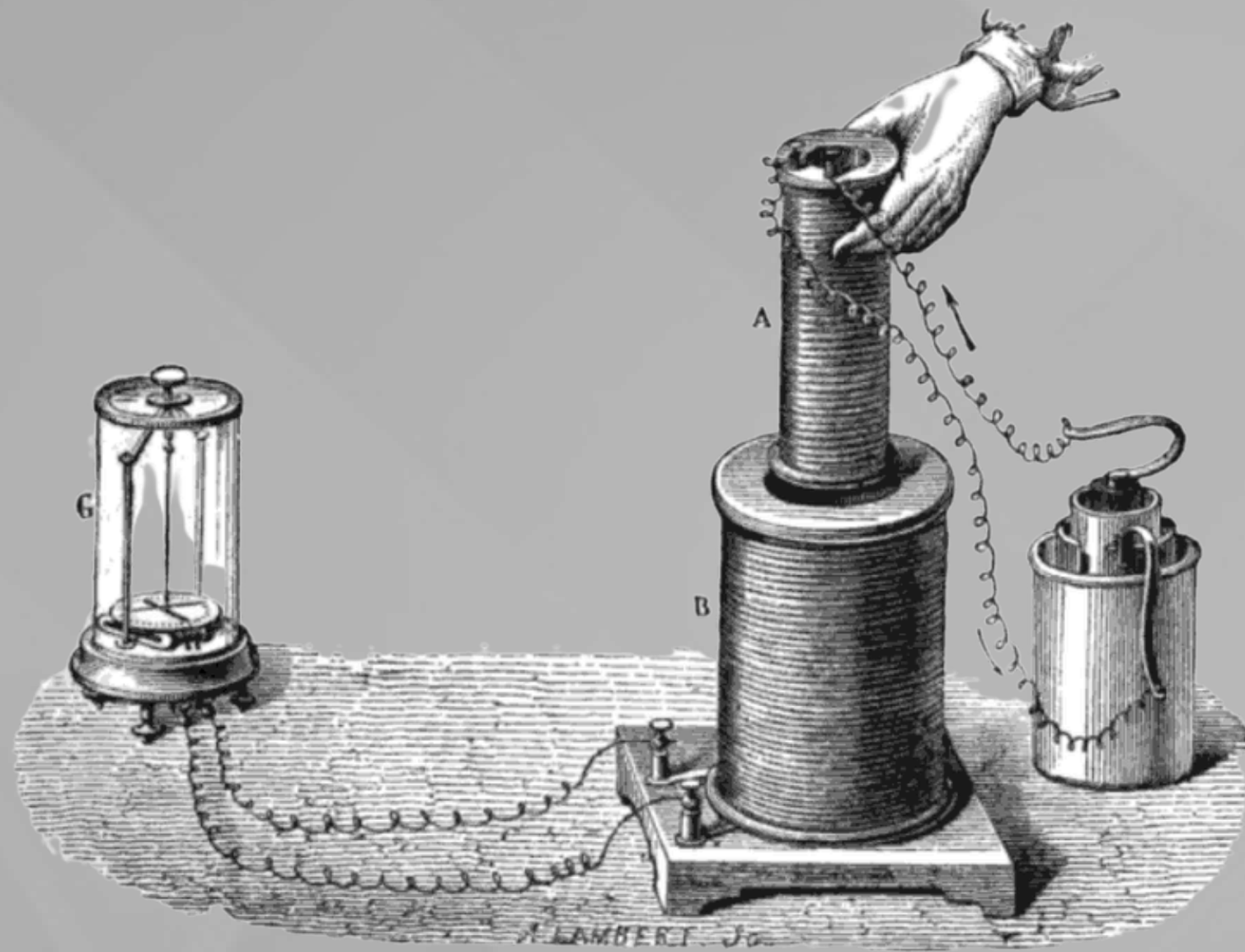
- English chemist and physicist
- Contributed to study of electrochemistry and electromagnetism.
- Main discoveries include:
 - Electromagnetic induction
 - Diamagnetism
 - Electrolysis

MICHAEL FARADAY 1831

- Wrapped wires around opposite sides of an iron ring
 - Change in magnetic field produces an electric current
 - Induction
- Magnetic Flux: The change needed to induce current
 - Move a magnet in and out of a coil of wires
- Originally rejected: Not formulated mathematically
 - James Clerk Maxwell (1862): Maxwell-Faraday equation

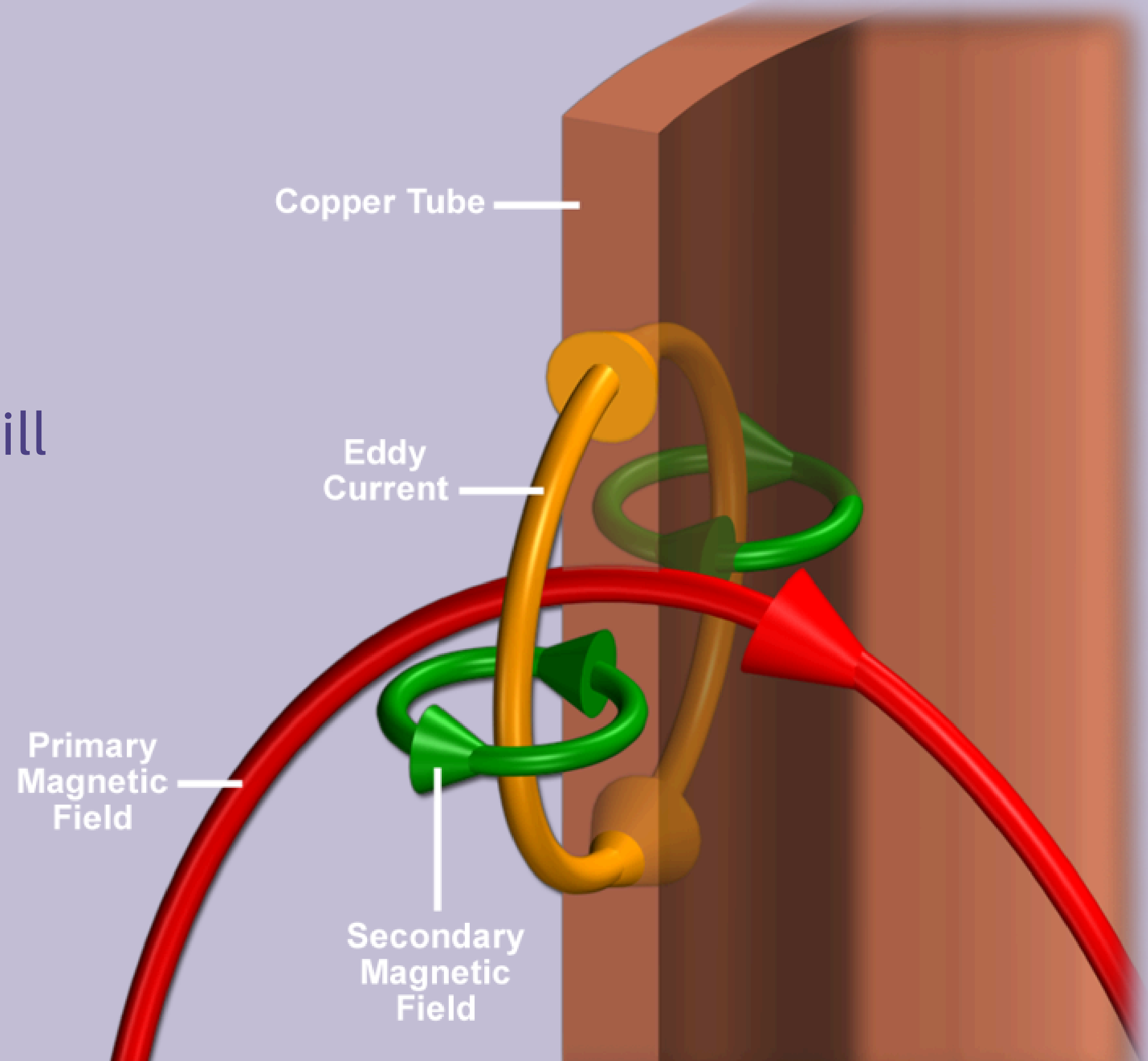


MAGNETIC FLUX



1834: EMIL LENZ

- Lenz's Law: An induced current in a wire (by flux) will flow to create a field that opposes the flux
 - Eddy currents created
- Used in magnetic braking systems
 - Rollercoasters
 - Electric car braking feedback





1900: SUPERCONDUCTIVITY

0 Ohms (Resistance)

TRADITIONAL METALS



0 Kelvin (Temperature)

1900: SUPERCONDUCTIVITY

0 Ohms (Resistance)

0 Kelvin (Temperature)

TRADITIONAL METALS



SUPERCONDUCTORS

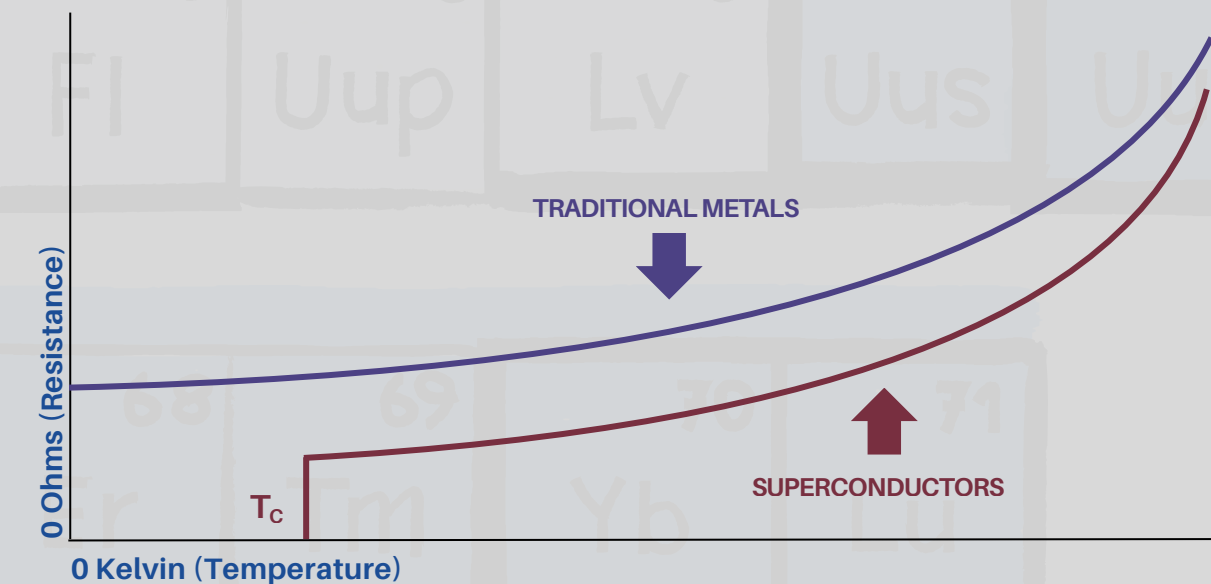


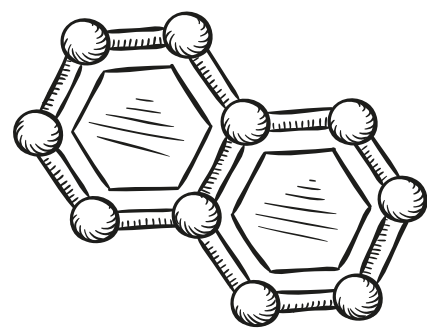
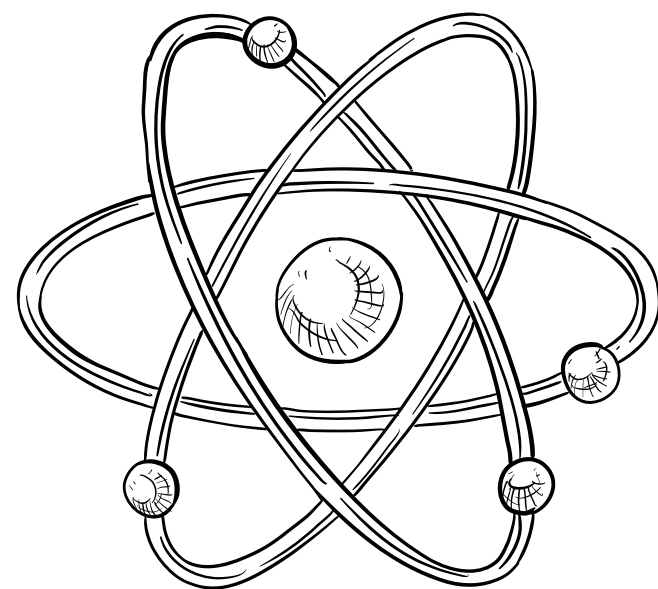
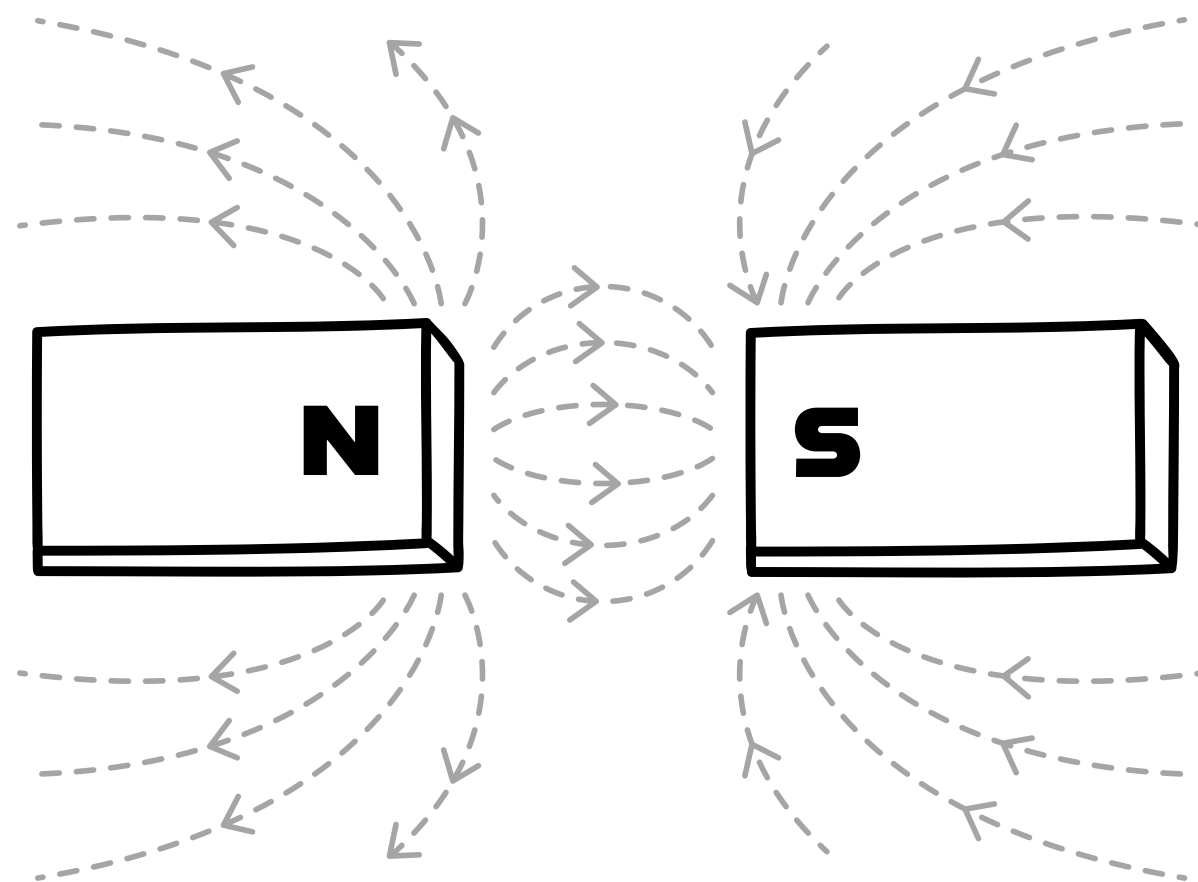
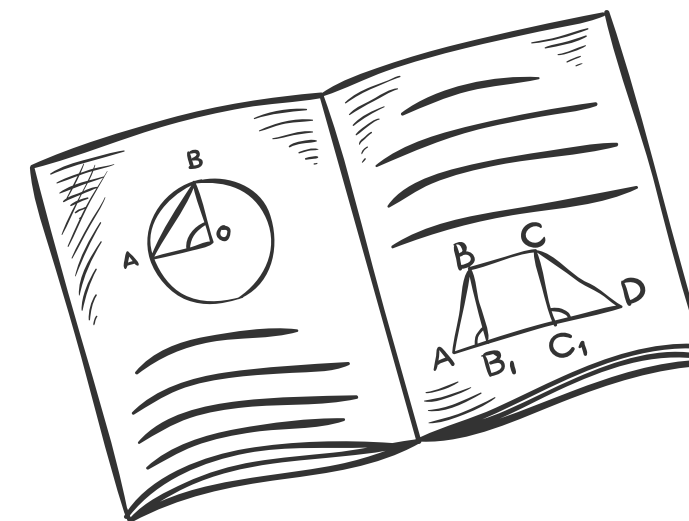
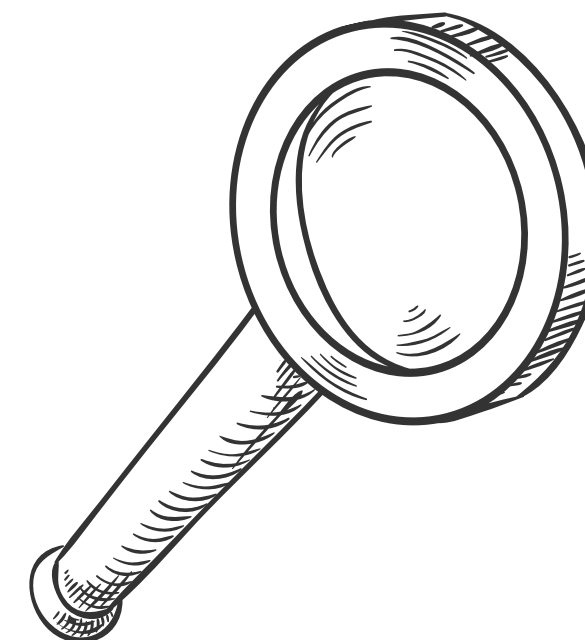
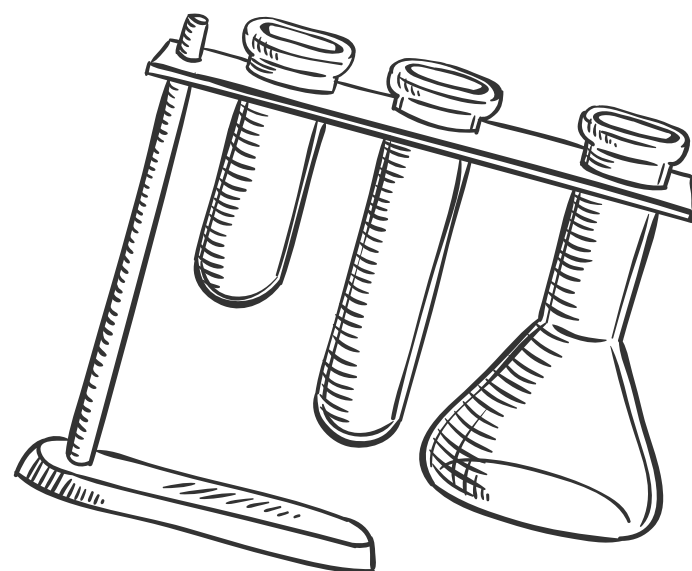
T_c

1900: SUPERCONDUCTIVITY

1957: BCS THEORY OF SUPERCONDUCTIVITY

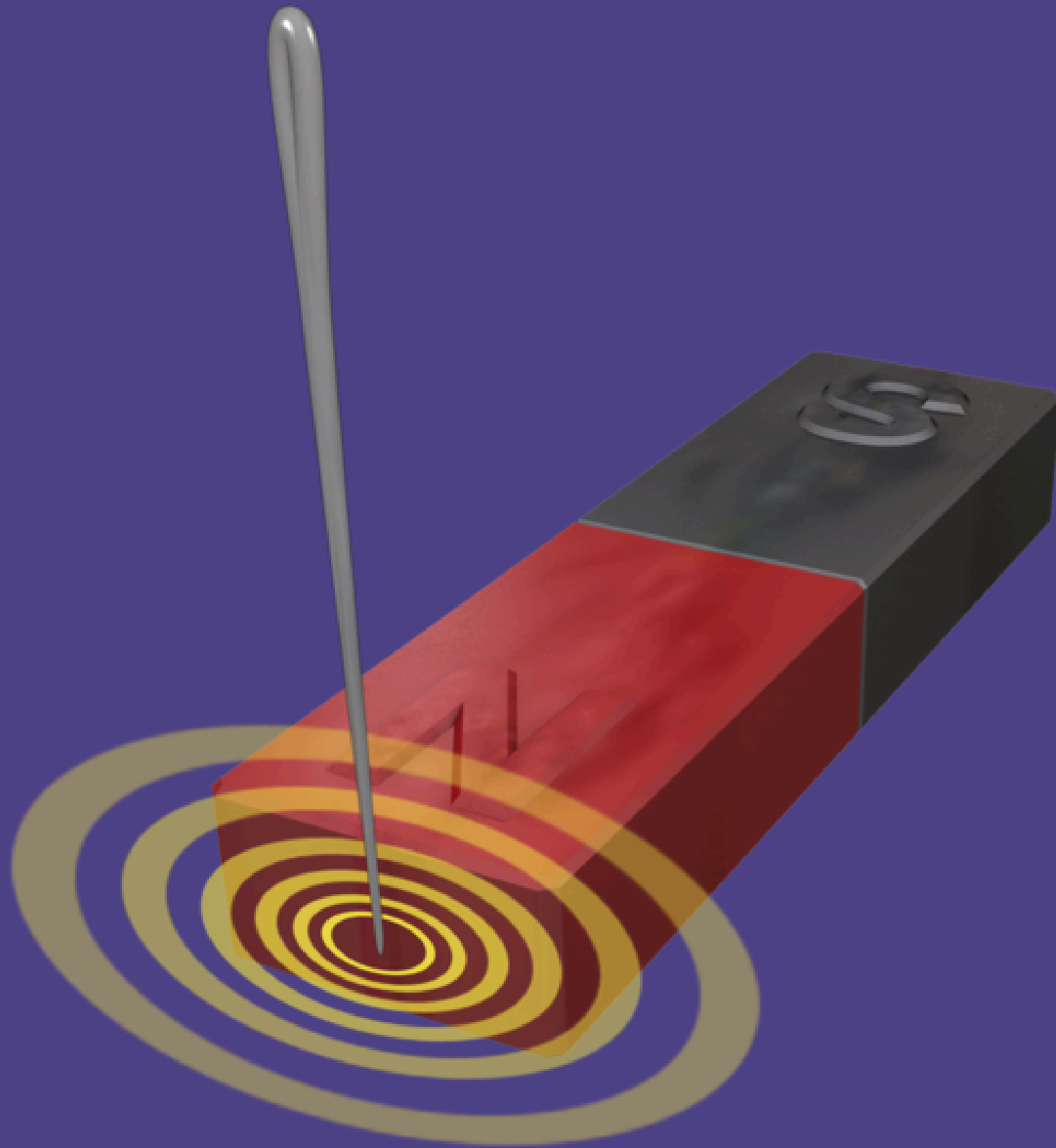
- BCS: Bardeen, Cooper, Schreiffer
 - At low temperatures, some metals lose resistance
 - Nucleus nearly stationary
- Superconductivity results from the formation of Cooper pairs
 - Two electrons partnered
 - One follows the other
 - Results in frictionless flow of electrons





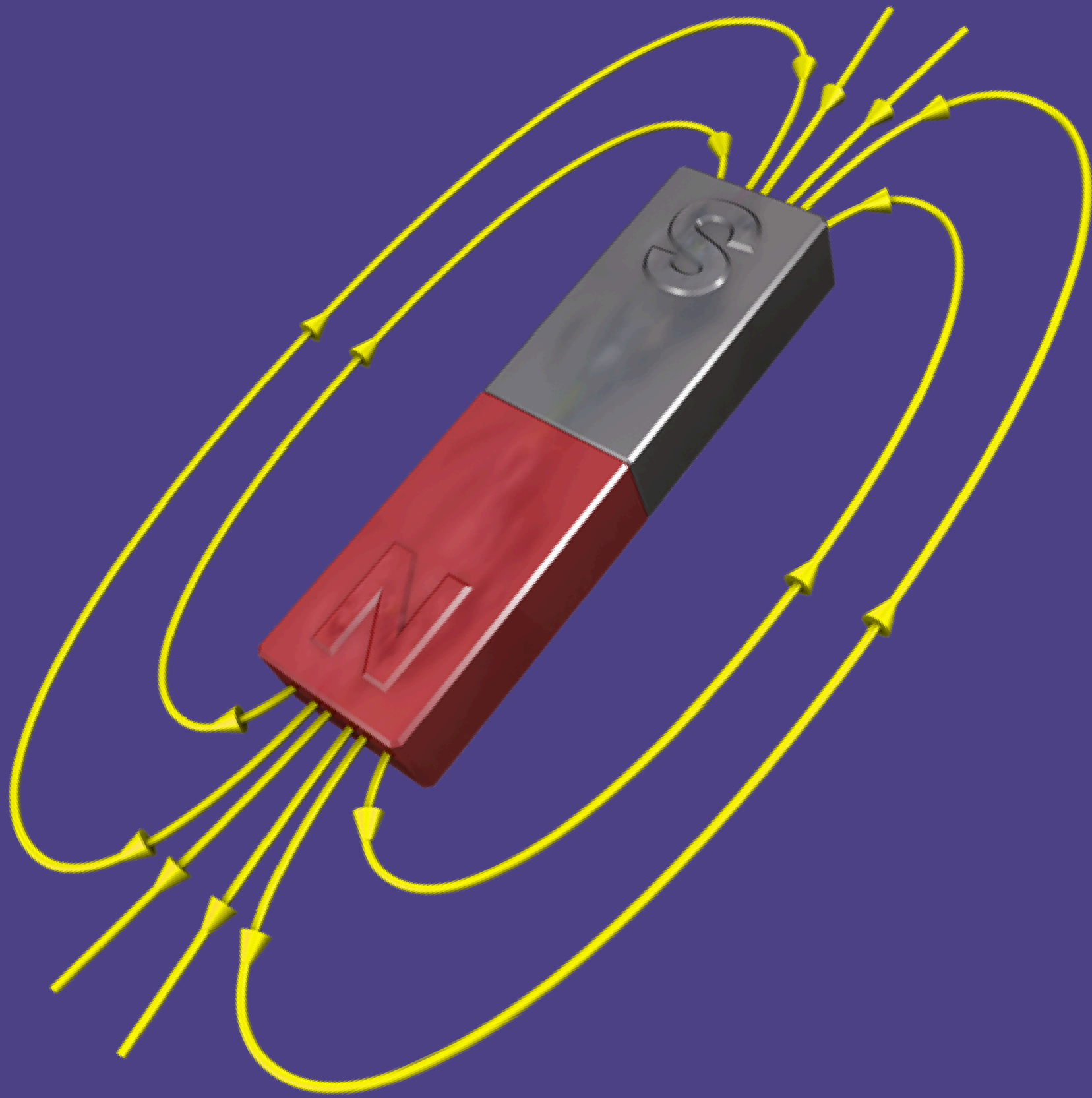
THE SCIENCE OF MAGNETISM

Magnets & Magnetic Fields



- All magnets have poles
 - North & South
 - Opposites attract
 - Likes repel
- But not really: Magnetic monopole
 - Ongoing research

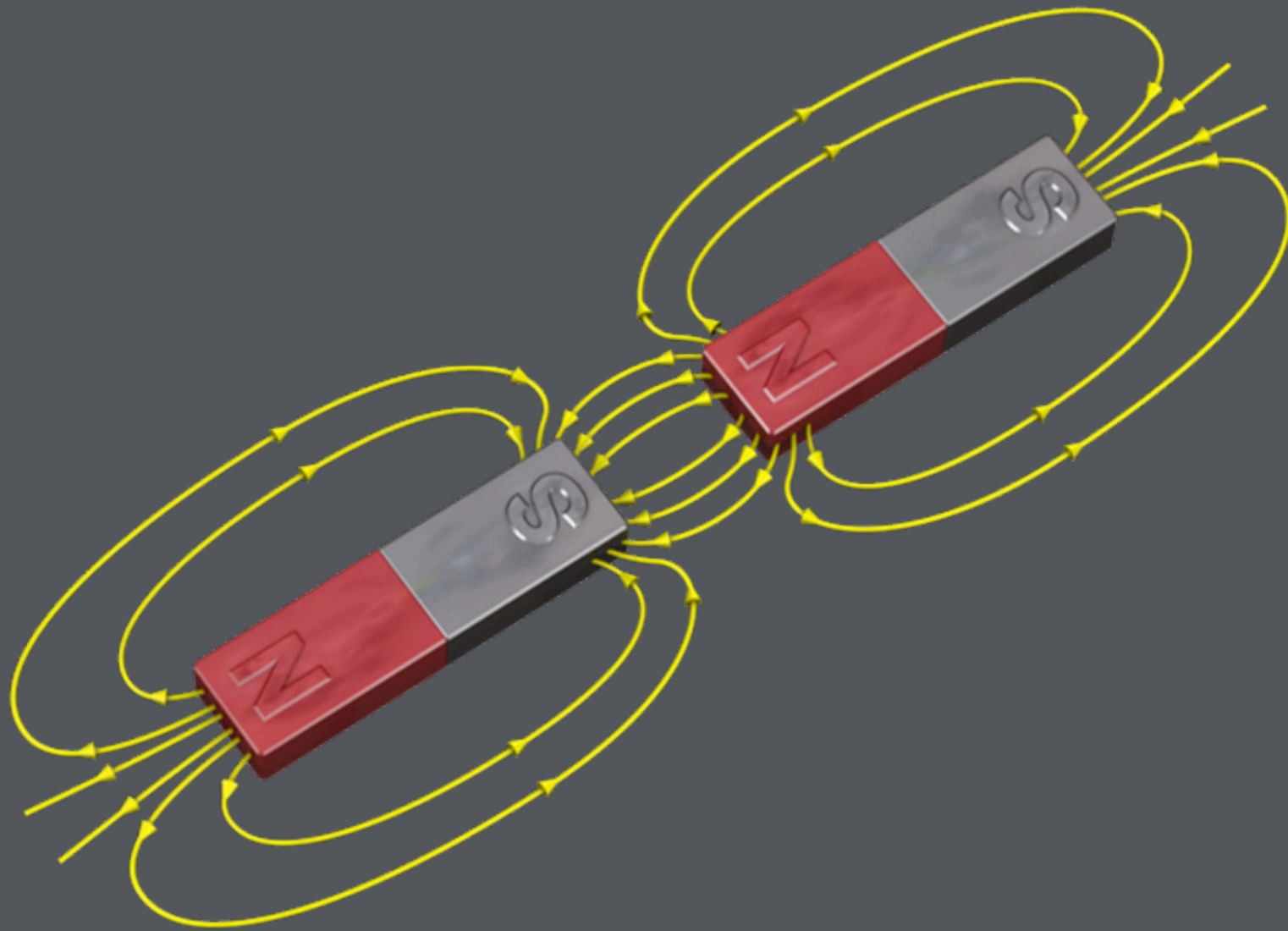
Magnets & Magnetic Fields



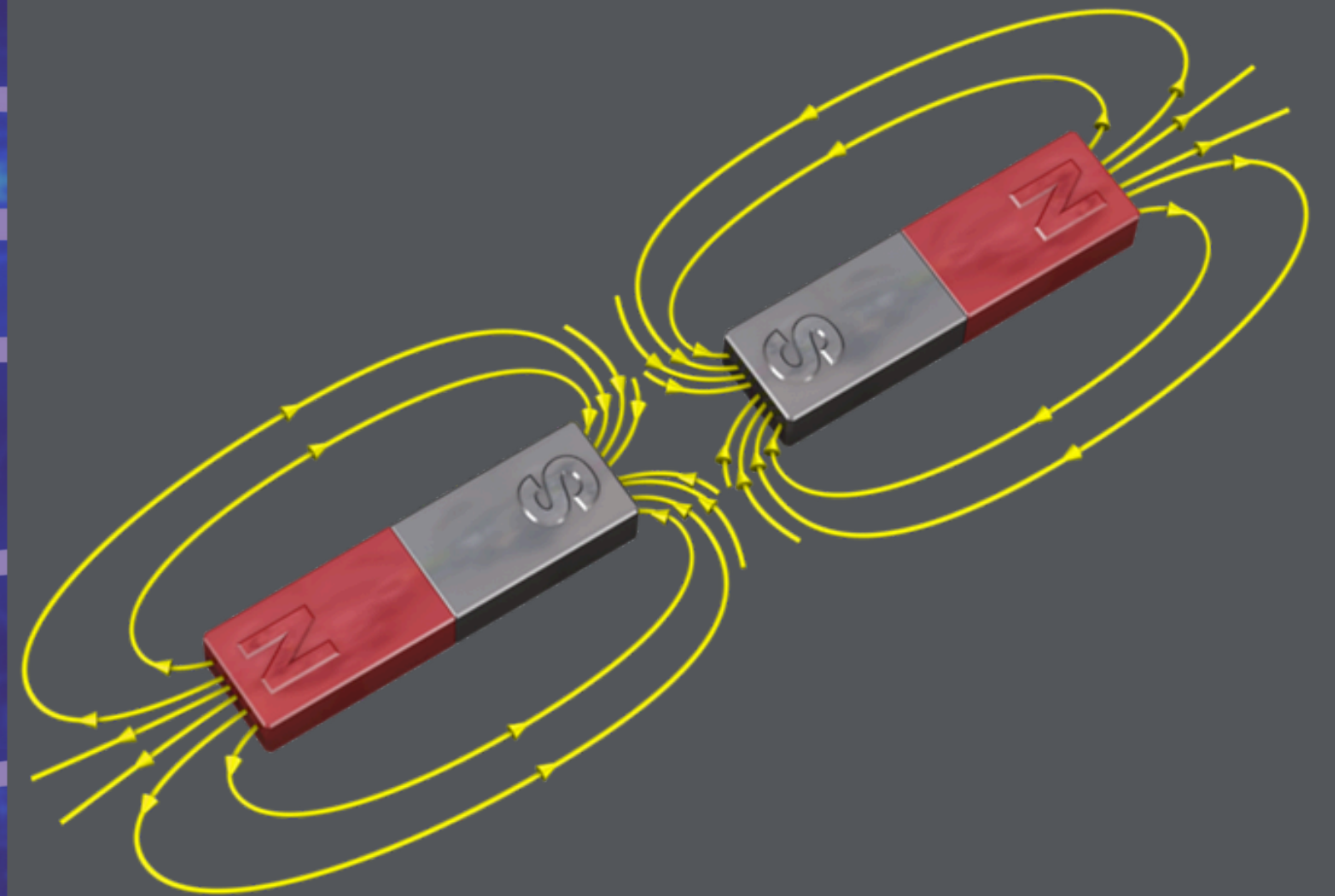
- All magnets have magnetic fields
 - Fields are responsible for attracting and repelling
- Magnetic field is a vector field
 - Has direction and magnitude

MAGNETS & MAGNETIC FIELDS

•▶ **MAGNETS ATTRACT** ◀•



•▶ **MAGNETS REPEL** ◀•



MAGNETS & MAGNETIC FIELDS



Sea turtles navigate across the ocean and return to their exact birthplace beaches by using Earth's magnetic field as both an internal compass and a geographic map.

MAGNETS & MAGNETIC FIELDS



Sea turtles navigate across the ocean and return to their exact birthplace beaches by using Earth's magnetic field as both an internal compass and a geographic map.



Hammerhead sharks use the Earth's magnetic field like a natural GPS to navigate long-distance migrations and return to exact locations year after year.

MAGNETS & MAGNETIC FIELDS



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Hammerhead sharks use the Earth's magnetic field like a natural GPS to navigate long-distance migrations and return to exact locations year after year.

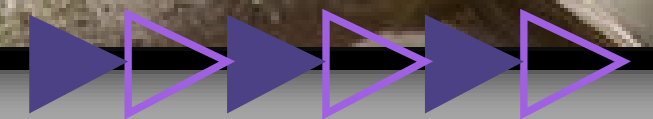


Birds use a special sense called magnetoreception to detect the Earth's magnetic field and navigate across long distances.

• ► MAGNETS & MAGNETIC FIELDS

Quantum Vision: Migratory songbirds (such as European robins) rely on a light-sensitive eye protein in their retinas.

When blue light hits the eye, quantum radical pairs form, allowing birds to literally "see" Earth's magnetic field as a faint visual pattern or glowing guide overlaid on their vision.



Arctic Fox

Vulpes lagopus

- Foxes listen and aligns with the angle of the sound waves.
- Protein in the eyes allows them to detect magnetic field.
- When they align to the north, they successfully pounce on their prey 74% of the time.
- If they align in any other direction, they are only successful 18% of the time.



PERIODIC TABLE OF ELEMENTS

IA

1
H
Hydrogen
1.00794

3
Li
Lithium
6.941

11
Na
Sodium
22.989767

19
K
Potassium
39.0983

37
Rb
Rubidium
85.4678

55
Cs
Cesium
132.90545

87
Fr
Francium
(223)

IIA

4
Be
Beryllium
9.012182

12
Mg
Magnesium
24.305

20
Ca
Calcium
40.078

38
Sr
Strontium
87.62

56
Ba
Barium
137.327

88
Ra
Radium
(226)

TABLE KEY

6
C
Carbon
12.011

Atomic Number

Symbol

Name

Atomic Mass

Chemical Group

CHEMICAL GROUP

Reactive Nonmetals	Metalloids
Alkali Metals	Noble Gases
Alkaline Earth Metals	Lanthanoids
Transition Metals	Actinoids
Post-Transition Metals	

STATE OF MATTER

H Gas H Liquid H Solid H Unknown

VIIIA

2
He
Helium
4.0026

10
Ne
Neon
20.1797

18
Ar
Argon
39.948

36
Kr
Krypton
83.8

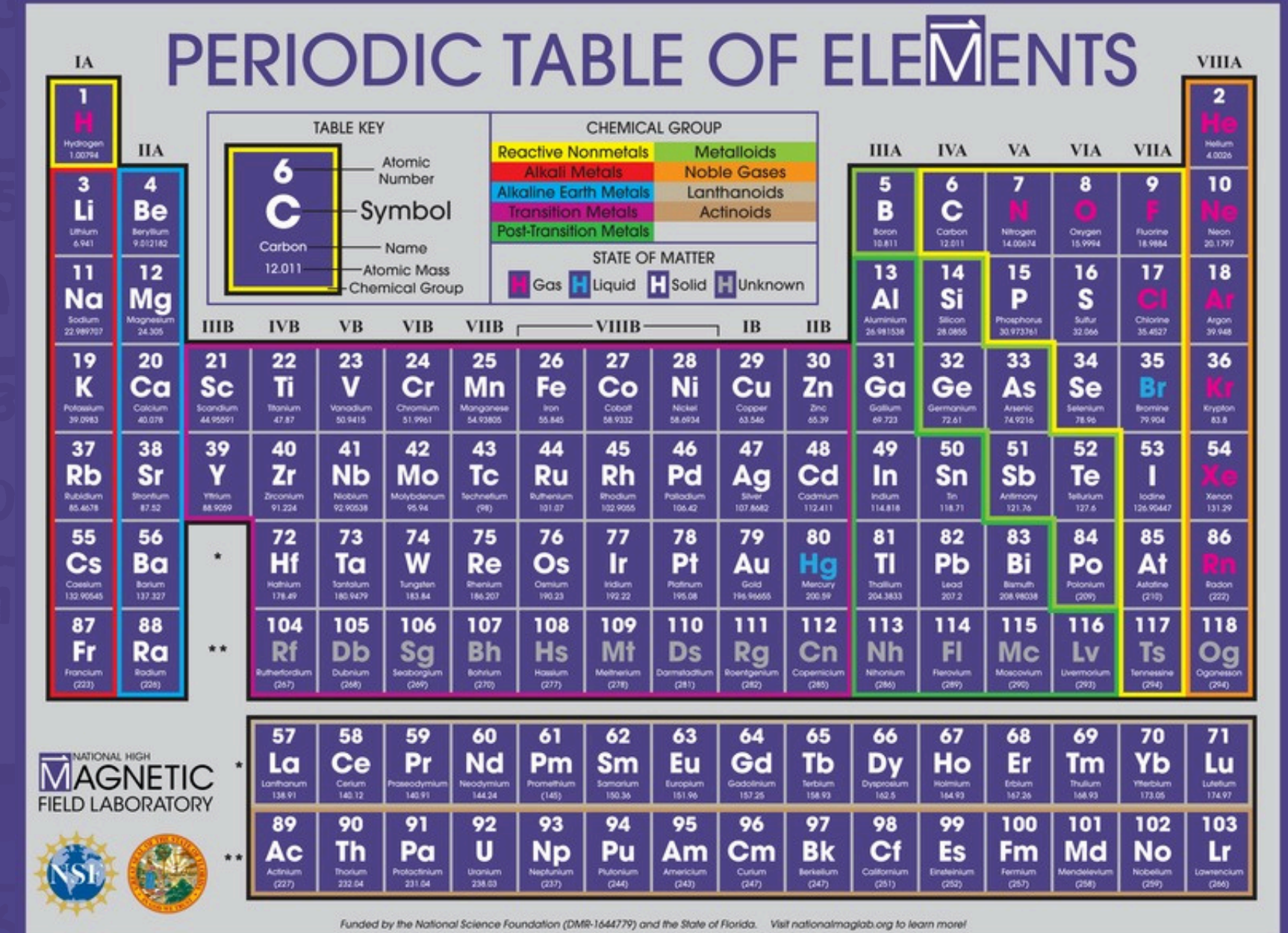
54
Xe
Xenon
131.29

86
Rn
Radon
(222)

		IIIB	IVB	VB	VIB	VII B	VIII B		IB	IIB			IIIA	IVA	VA	VIA	VIIA	
		21 Sc Scandium 44.95591	22 Ti Titanium 47.87	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.93805	26 Fe Iron 55.845	27 Co Cobalt 58.9332	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39		5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.00644	8 O Oxygen 15.9994	9 F Fluorine 18.9984	10 Ne Neon 20.1797
		39 Y Yttrium 88.90584	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411		13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.06	17 Cl Chlorine 35.453	18 Ar Argon 39.948
		* 72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.96655	80 Hg Mercury 200.59			49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.75	52 Te Tellurium 127.6	53 I Iodine 126.90447	54 Xe Xenon 131.29
		** 104 Rf Rutherfordium (261)	105 Db Dubnium (268)	106 Sg Seaborgium (266)	107 Bh Bohrium (270)	108 Hs Hassium (277)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (285)			81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
												113 Nh Nihonium (284)	114 Fl Flerovium (289)	115 Mc Moscovium (290)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)	
		57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.5	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97		
		89 Ac Actinium (227)	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californ							

MAGNETISM

- 3 metals are naturally magnetic at room temperature
 - Iron, Nickel, Cobalt



MAGNETISM

- 3 metals are naturally magnetic at room temperature
 - Iron, Nickel, Cobalt
- Two more are magnetic at lower temperatures
 - Gadolinium (65 F and below)
 - Dysprosium (-301 F and below)

PERIODIC TABLE OF ELEMENTS

IA

1
H
Hydrogen
1.00794

IIB

2
He
Helium
4.0026

IIA

3
Li
Lithium
6.941

IIIA

4
Be
Beryllium
9.012182

IIIB

5
B
Boron
10.811

IVB

6
C
Carbon
12.011

V

7
N
Nitrogen
14.00644

VB

8
O
Oxygen
15.9994

VIB

9
F
Fluorine
18.9984

VII

10
Ne
Neon
20.1797

VIII

11
Na
Sodium
22.989767

IX

12
Mg
Magnesium
24.305

X

13
Al
Aluminum
26.981538

XI

14
Si
Silicon
28.0855

XII

15
P
Phosphorus
30.973761

XIII

16
S
Sulfur
32.06

XIV

17
Cl
Chlorine
35.4527

XV

18
Ar
Argon
39.948

XVI

19
K
Potassium
39.0983

XVII

20
Ca
Calcium
40.078

XVIII

21
Sc
Scandium
44.95591

XIX

22
Ti
Titanium
47.87

XX

23
V
Vanadium
50.9415

XXI

24
Cr
Chromium
51.9961

XXII

25
Mn
Manganese
54.93805

XXIII

26
Fe
Iron
55.845

XXIV

27
Co
Cobalt
58.9332

XXV

28
Ni
Nickel
58.6934

XXVI

29
Cu
Copper
63.546

XXVII

30
Zn
Zinc
65.39

XXVIII

31
Ga
Gallium
69.723

XXIX

32
Ge
Germanium
72.61

XXX

33
As
Arsenic
74.9216

XXXI

34
Se
Selenium
78.96

XXXII

35
Br
Bromine
79.904

XXXIII

36
Kr
Krypton
83.8

XXXIV

37
Rb
Rubidium
85.4678

XXXV

38
Sr
Strontium
87.62

XXXVI

39
Y
Yttrium
88.9059

XXXVII

40
Zr
Zirconium
91.224

XXXVIII

41
Nb
Niobium
92.90638

XXXIX

42
Mo
Molybdenum
95.94

XL

43
Tc
Technetium
(98)

XLI

44
Ru
Ruthenium
101.07

XLII

45
Rh
Rhodium
102.9055

XLIII

46
Pd
Palladium
106.42

XLIV

47
Ag
Silver
107.8682

XLV

48
Cd
Cadmium
112.411

XLVI

49
In
Indium
114.818

XLVII

50
Sn
Tin
118.71

XLVIII

51
Sb
Antimony
121.76

XLIX

52
Te
Tellurium
127.6

L

53
I
Iodine
126.90447

LI

54
Xe
Xenon
131.29

LII

55
Cs
Cesium
132.90545

LIII

56
Ba
Barium
137.327

LIV

57
La
Lanthanum
138.91

LVI

58
Ce
Cerium
140.12

LVII

59
Pr
Praseodymium
140.91

LXIII

60
Nd
Neodymium
144.24

LXIV

61
Pm
Promethium
(145)

LXV

62
Sm
Samarium
150.36

LXVI

63
Eu
Europium
151.96

LXVII

64
Gd
Gadolinium
157.25

LXVIII

65
Tb
Terbium
158.93

LXIX

66
Dy
Dysprosium
162.5

LXX

67
Ho
Holmium
164.93

LXXI

68
Er
Erbium
167.26

LXXII

69
Tm
Thulium
168.93

LXXIII

70
Yb
Ytterbium
173.05

LXXIV

71
Lu
Lutetium
174.97

LXXV

72
Hf
Hafnium
178.49

LXXVI

73
Ta
Tantalum
180.9479

LXXVII

74
W
Tungsten
183.84

LXXVIII

75
Re
Rhenium
186.207

LXXIX

76
Os
Osmium
190.23

LXXX

77
Ir
Iridium
192.22

LXXXI

78
Pt
Platinum
195.08

LXXXII

79
Au
Gold
196.96655

LXXXIII

80
Hg
Mercury
200.59

LXXXIV

81
Tl
Thallium
204.3833

LXXXV

82
Pb
Lead
207.2

LXXXVI

83
Bi
Bismuth
208.98038

LXXXVII

84
Po
Polonium
(209)

LXXXVIII

85
At
Astatine
(210)

LXXXIX

86
Rn
Radon
(222)

LXXXX

87
Fr
Francium
(223)

LXXXXI

88
Ra
Radium
(226)

LXXXXII

89
Ac
Actinium
(227)

LXXXXIII

90
Th
Thorium
232.04

LXXXXIV

91
Pa
Protactinium
231.04

LXXXXV

92
U
Uranium
238.03

LXXXXVI

93
Np
Neptunium
(237)

LXXXXVII

94
Pu
Plutonium
(244)

LXXXXVIII

95
Am
Americium
(243)

LXXXXIX

96
Cm
Curium
(247)

LXXXXX

97
Bk
Berkelium
(247)

LXXXXXI

98
Cf
Californium
(251)

LXXXXXII

99
Es
Einsteinium
(252)

LXXXXXIII

100
Fm
Fermium
(257)

LXXXXXIV

101
Md
Mendelevium
(258)

LXXXXXV

102
No
Nobelium
(259)

LXXXXXVI

103
Lr
Lawrencium
(260)

LXXXXXVII

104
Rf
Rutherfordium
(261)

LXXXXXVIII

105
Db
Dubnium
(268)

LXXXXXIX

106
Sg
Seaborgium
(269)

LXXXXXX

107
Bh
Bohrium
(270)

LXXXXXXI

108
Hs
Hassium
(277)

LXXXXXXII

109
Mt
Meitnerium
(278)

LXXXXXXIII

110
Ds
Darmstadtium
(281)

LXXXXXXIV

111
Rg
Roentgenium
(282)

LXXXXXXV

112
Cn
Copernicium
(285)

LXXXXXXVI

113
Nh
Nihonium
(286)

LXXXXXXVII

114
Fl
Flerovium
(289)

LXXXXXXVIII

115
Mc
Moscovium
(290)

LXXXXXXIX

116
Lv
Livermorium
(293)

LXXXXXXX

117
Ts
Tennessine
(294)

LXXXXXXXI

118
Og
Oganesson
(294)

TABLE KEY

6
C
Carbon
12.011

Atomic Number

Symbol

Name

Atomic Mass

Chemical Group

CHEMICAL GROUP

Reactive Nonmetals

Alkali Metals

Alkaline Earth Metals

Transition Metals

Post-Transition Metals

Metalloids

Noble Gases

Lanthanoids

Actinoids

STATE OF MATTER

H Gas

H Liquid

H Solid

H Unknown

NATIONAL HIGH MAGNETIC FIELD LABORATORY

NSF

Funded by the National Science Foundation (DMR-1644779) and the State of Florida. Visit nationalmaglab.org to learn more!

MAGNETISM

- 3 metals are naturally magnetic at room temperature
 - Iron, Nickel, Cobalt
- Two more are magnetic at lower temperatures
 - Gadolinium (65 F and below)
 - Dysprosium (-301 F and below)
- One more magnetic at abnormal conditions
 - Ruthenium (In unnatural form)

[illegible]

MAGNETISM

- 3 metals are naturally magnetic at room temperature
 - Iron, Nickel, Cobalt
- Two more are magnetic at lower temperatures
 - Gadolinium (65 F and below)
 - Dysprosium (-301 F and below)
- One more magnetic at abnormal conditions
 - Ruthenium (In unnatural form)
- Many are magnetic as alloys
 - Neodymium and other Rare-Earth elements

PERIODIC TABLE OF ELEMENTS

TABLE KEY

6
C
Carbon
12.011

Atomic Number
Symbol
Name
Atomic Mass
Chemical Group

CHEMICAL GROUP

Reactive Nonmetals
Alkali Metals
Transition Metals
Post-Transition Metals

Metalloids
Noble Gases
Lanthanoids
Actinoids

STATE OF MATTER

H Gas H Liquid H Solid H Unknown

IA **IIA** **IIIB** **IVB** **VB** **VIB** **VIIA** **VIIIA** **IIIB** **IVB** **VB** **VIB** **VIIA** **VIIIA** **IIA** **IA**

1 H Hydrogen 1.00794 **2** He Helium 4.0026

3 Li Lithium 6.941 **4** Be Beryllium 9.012182 **5** B Boron 10.811 **6** C Carbon 12.011 **7** N Nitrogen 14.00644 **8** O Oxygen 15.9994 **9** F Fluorine 18.9984 **10** Ne Neon 20.1797

11 Na Sodium 22.989767 **12** Mg Magnesium 24.305 **13** Al Aluminum 26.981538 **14** Si Silicon 28.0855 **15** P Phosphorus 30.973761 **16** S Sulfur 32.06 **17** Cl Chlorine 35.4527 **18** Ar Argon 39.948

19 K Potassium 39.0983 **20** Ca Calcium 40.078 **21** Sc Scandium 44.95591 **22** Ti Titanium 47.87 **23** V Vanadium 50.9415 **24** Cr Chromium 51.9961 **25** Mn Manganese 54.93805 **26** Fe Iron 55.845 **27** Co Cobalt 58.9332 **28** Ni Nickel 58.6934 **29** Cu Copper 63.546 **30** Zn Zinc 65.39

37 Rb Rubidium 85.4678 **38** Sr Strontium 87.62 **39** Y Yttrium 88.90584 **40** Zr Zirconium 91.224 **41** Nb Niobium 92.90638 **42** Mo Molybdenum 95.94 **43** Tc Technetium (98) **44** Ru Ruthenium 101.07 **45** Rh Rhodium 102.9055 **46** Pd Palladium 106.42 **47** Ag Silver 107.8682 **48** Cd Cadmium 112.411

55 Cs Cesium 132.90545 **56** Ba Barium 137.327 **72** Hf Hafnium 178.49 **73** Ta Tantalum 180.9479 **74** W Tungsten 183.84 **75** Re Rhenium 186.207 **76** Os Osmium 190.23 **77** Ir Iridium 192.22 **78** Pt Platinum 195.08 **79** Au Gold 196.96655 **80** Hg Mercury 200.59

87 Fr Francium (223) **88** Ra Radium (226) **104** Rf Rutherfordium (261) **105** Db Dubnium (268) **106** Sg Seaborgium (266) **107** Bh Bohrium (270) **108** Hs Hassium (277) **109** Mt Meitnerium (276) **110** Ds Darmstadtium (281) **111** Rg Roentgenium (282) **112** Cn Copernicium (285)

81 Tl Thallium 204.3833 **82** Pb Lead 207.2 **83** Bi Bismuth 208.98038 **84** Po Polonium (209) **85** At Astatine (210) **86** Rn Radon (222)

113 Nh Nihonium (284) **114** Fl Flerovium (289) **115** Mc Moscovium (288) **116** Lv Livermorium (293) **117** Ts Tennessine (294) **118** Og Oganesson (294)

57 La Lanthanum 138.91 **58** Ce Cerium 140.12 **59** Pr Praseodymium 140.91 **60** Nd Neodymium 144.24 **61** Pm Promethium (145) **62** Sm Samarium 150.36 **63** Eu Europium 151.96 **64** Gd Gadolinium 157.25 **65** Tb Terbium 158.93 **66** Dy Dysprosium 162.5 **67** Ho Holmium 164.93 **68** Er Erbium 167.26 **69** Tm Thulium 168.93 **70** Yb Ytterbium 173.05 **71** Lu Lutetium 174.97

89 Ac Actinium (227) **90** Th Thorium 232.04 **91** Pa Protactinium 231.04 **92** U Uranium 238.03 **93** Np Neptunium (237) **94** Pu Plutonium (244) **95** Am Americium (243) **96** Cm Curium (247) **97** Bk Berkelium (247) **98** Cf Californium (251) **99** Es Einsteinium (252) **100** Fm Fermium (257) **101** Md Mendelevium (258) **102** No Nobelium (259) **103** Lr Lawrencium (260)

NATIONAL HIGH MAGNETIC FIELD LABORATORY

NSF

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NAME THIS MOVIE



MONSTERS, INC.

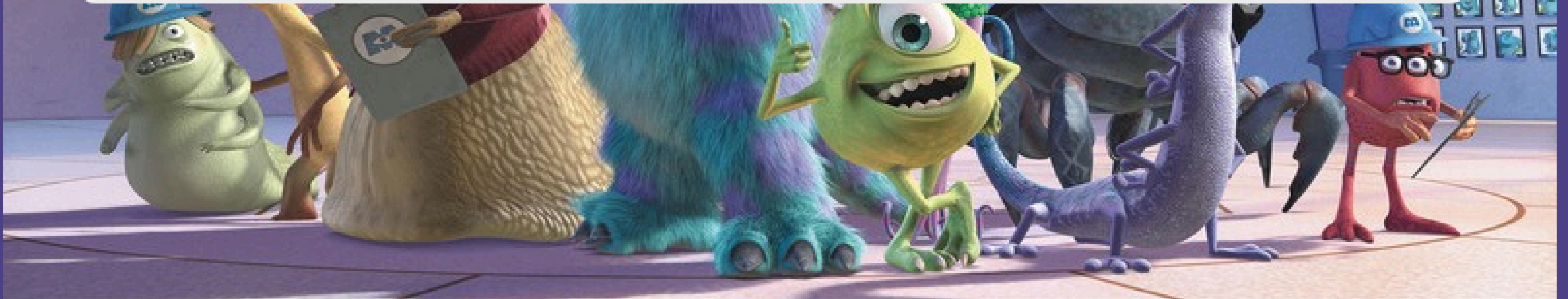


~~MONSTERS, INC.~~



MONSTERS, INC.

MAGNETS, INC.



~~MONSTERS, INC.~~

MAGNETS, INC.

INC. = Iron, Nickel, Cobalt

Permanent Magnets

- Almost always keep their field
- Fields can be lost
 - Curie point (Heat)
 - Electric current (Degauss)
 - Hitting it (Blunt force)

Permanent & Temporary Magnets

Permanent Magnets

- Almost always keep their field
- Fields can be lost
 - Curie point (Heat)
 - Electric current (Degauss)
 - Hitting it (Blunt force)

Temporary Magnets

- Will keep magnetic field until tampered with
- Anything that is magnetic, but will not keep its field
- Examples:
 - Paperclips, scissors, staples, thumb tacks, pins, screwdrivers, refrigerator door, car doors, etc...

Permanent & Temporary Magnets

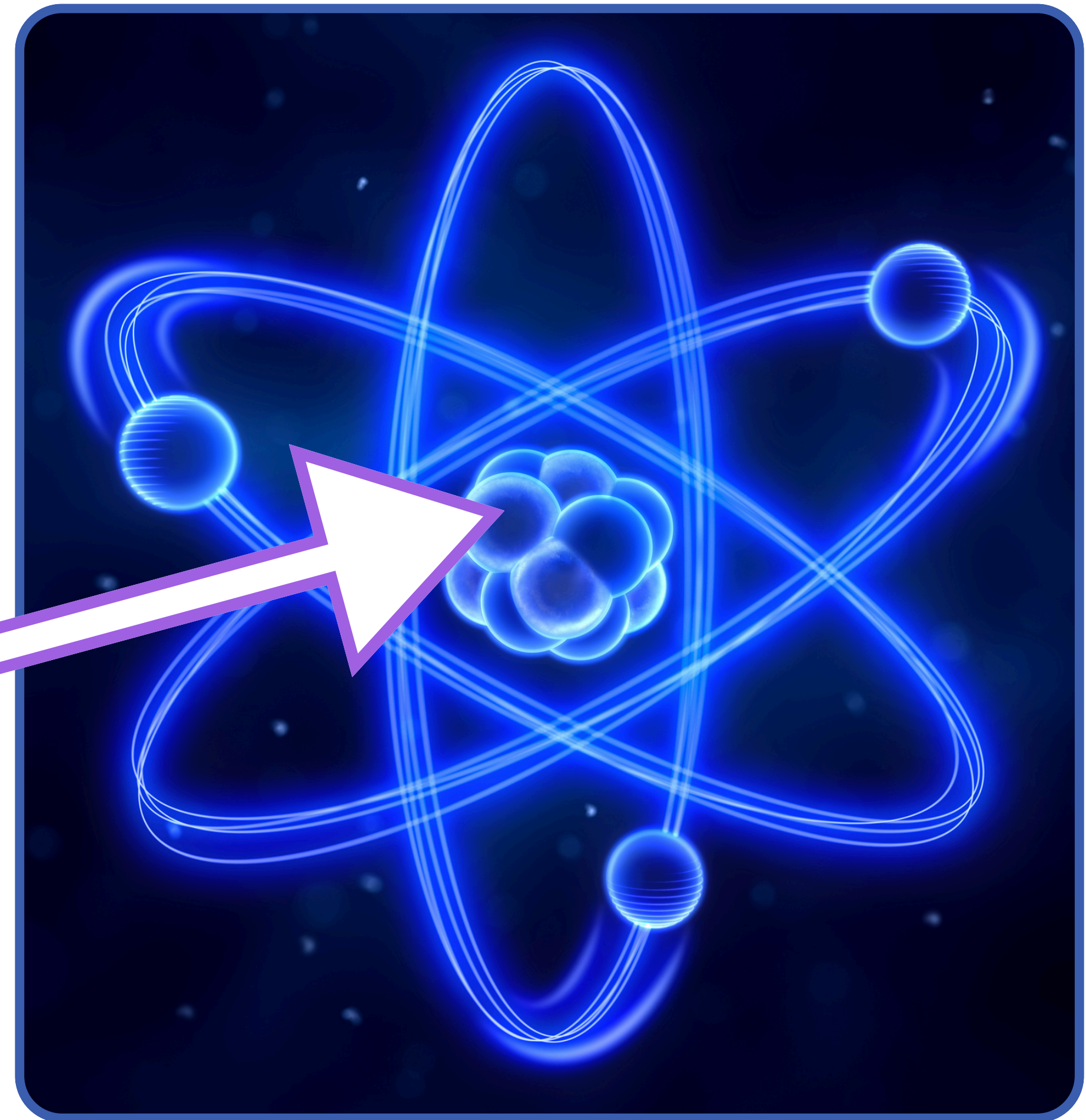
MAKING MAGNETISM

- Name atom comes from Atomos, Greek for Indestructible (not really)
- The atom is divisible
 - Proton
 - Neutron
 - Electron



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- The atom is divisible
 - Proton
 - Neutron
 - Electron



MAKING MAGNETISM

**Motion of charged
particles creates
magnetic fields**

**Electrons are charged
particles and are in
motion**

**Electrons create
magnetic fields**

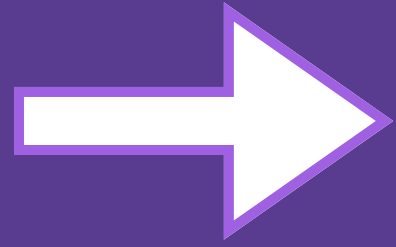


MAKING MAGNETISM



Magnetic domains
with entropy

MAKING MAGNETISM



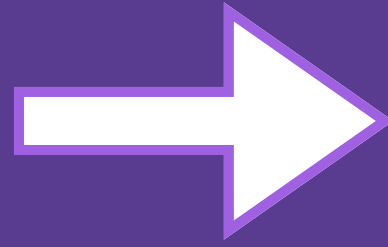
Magnetic domains
with entropy

Magnetic domains
with an external field
applied

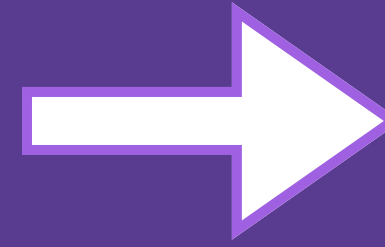
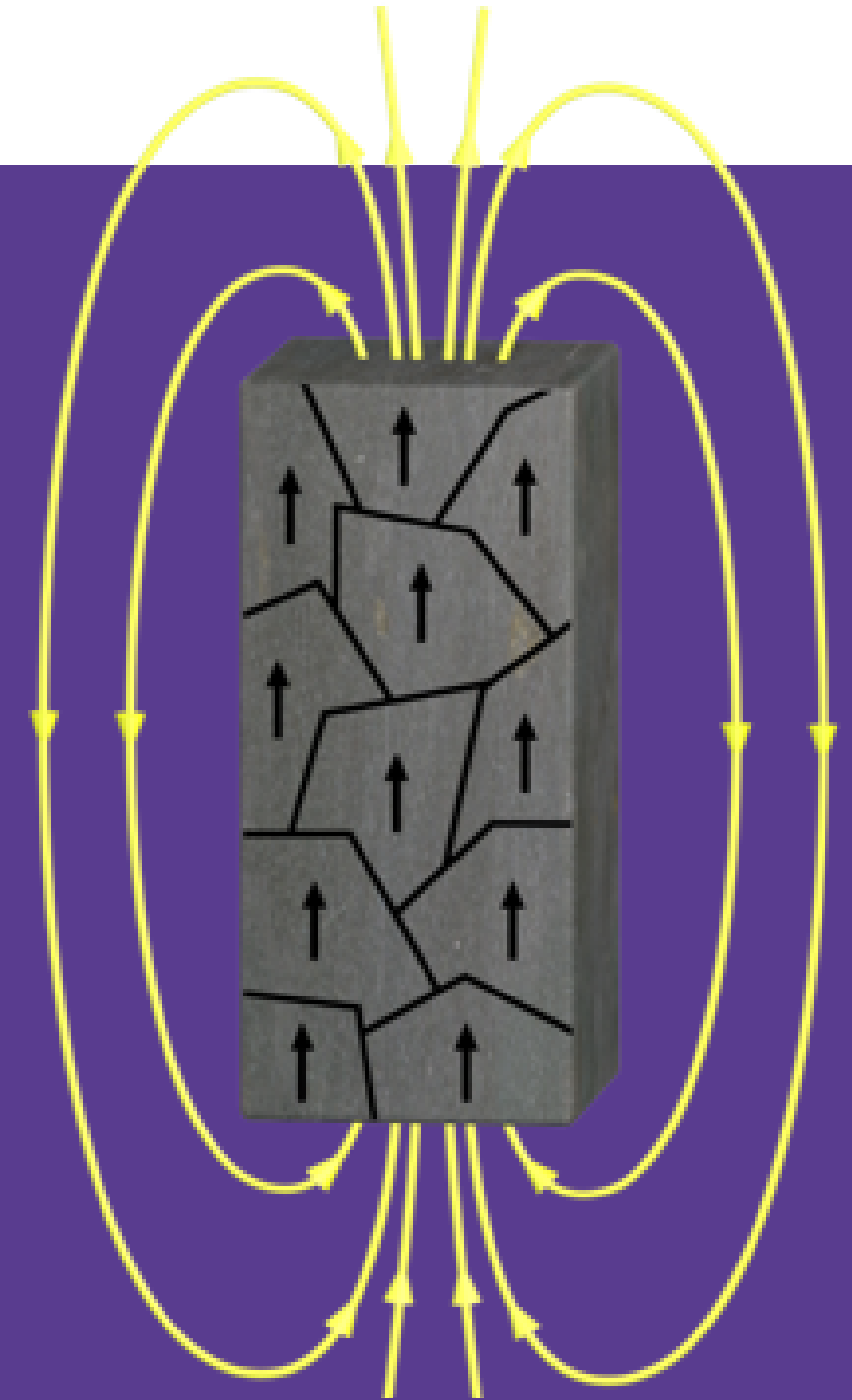
MAKING MAGNETISM



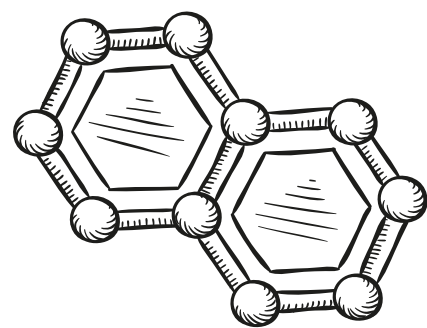
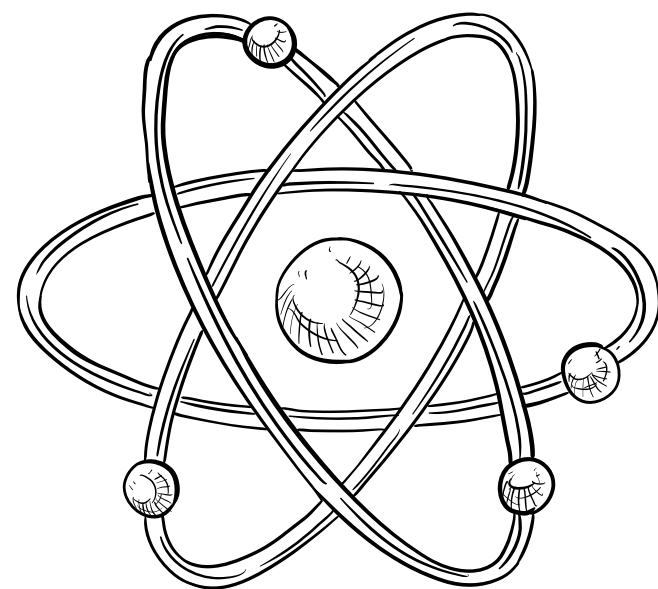
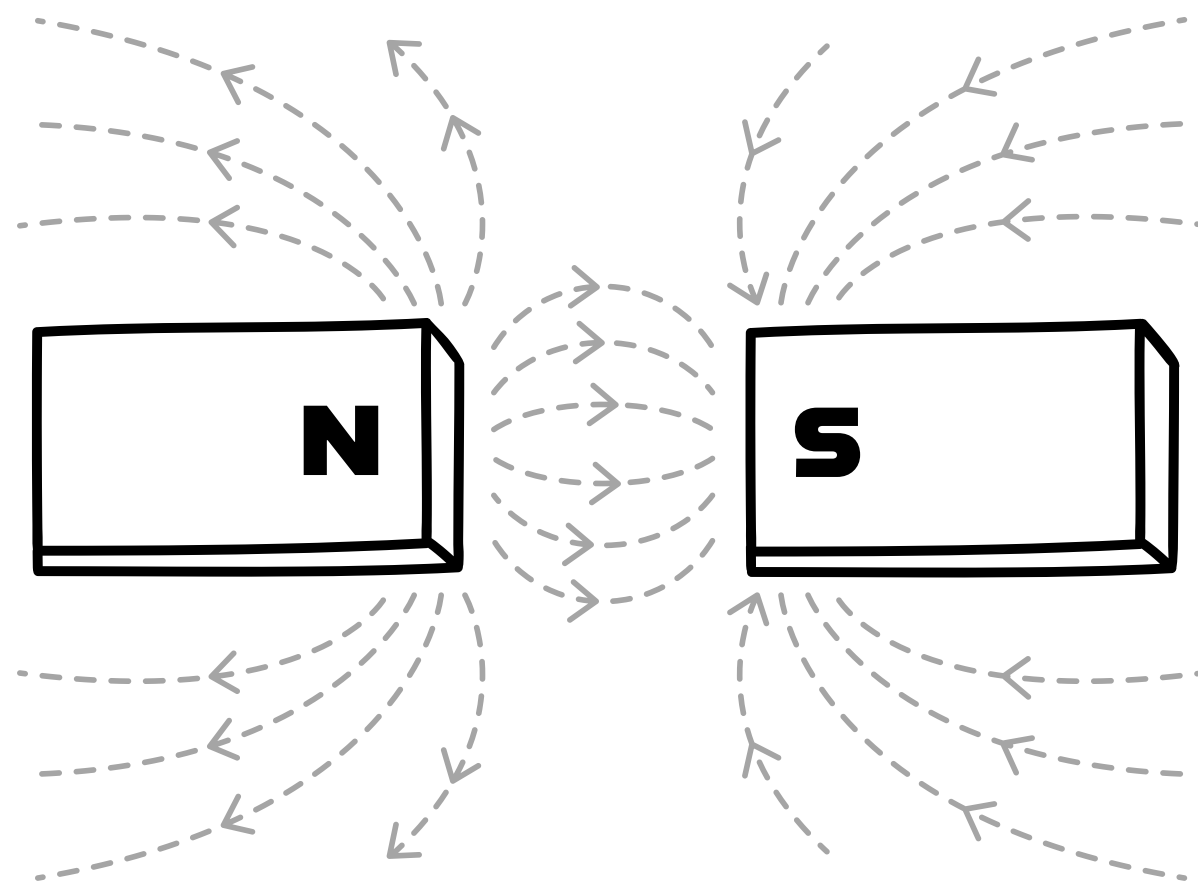
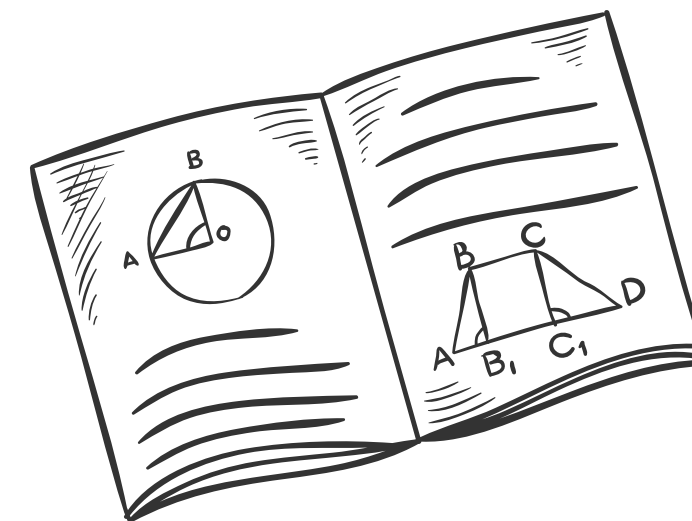
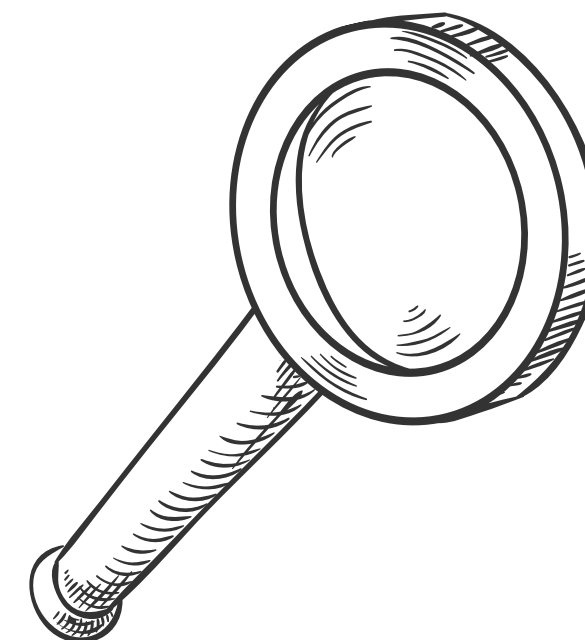
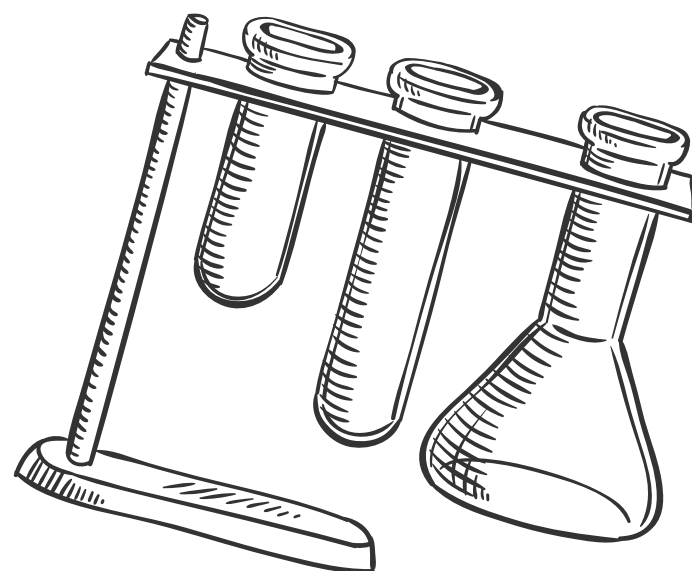
Magnetic domains
with entropy



Magnetic domains
with an external field
applied



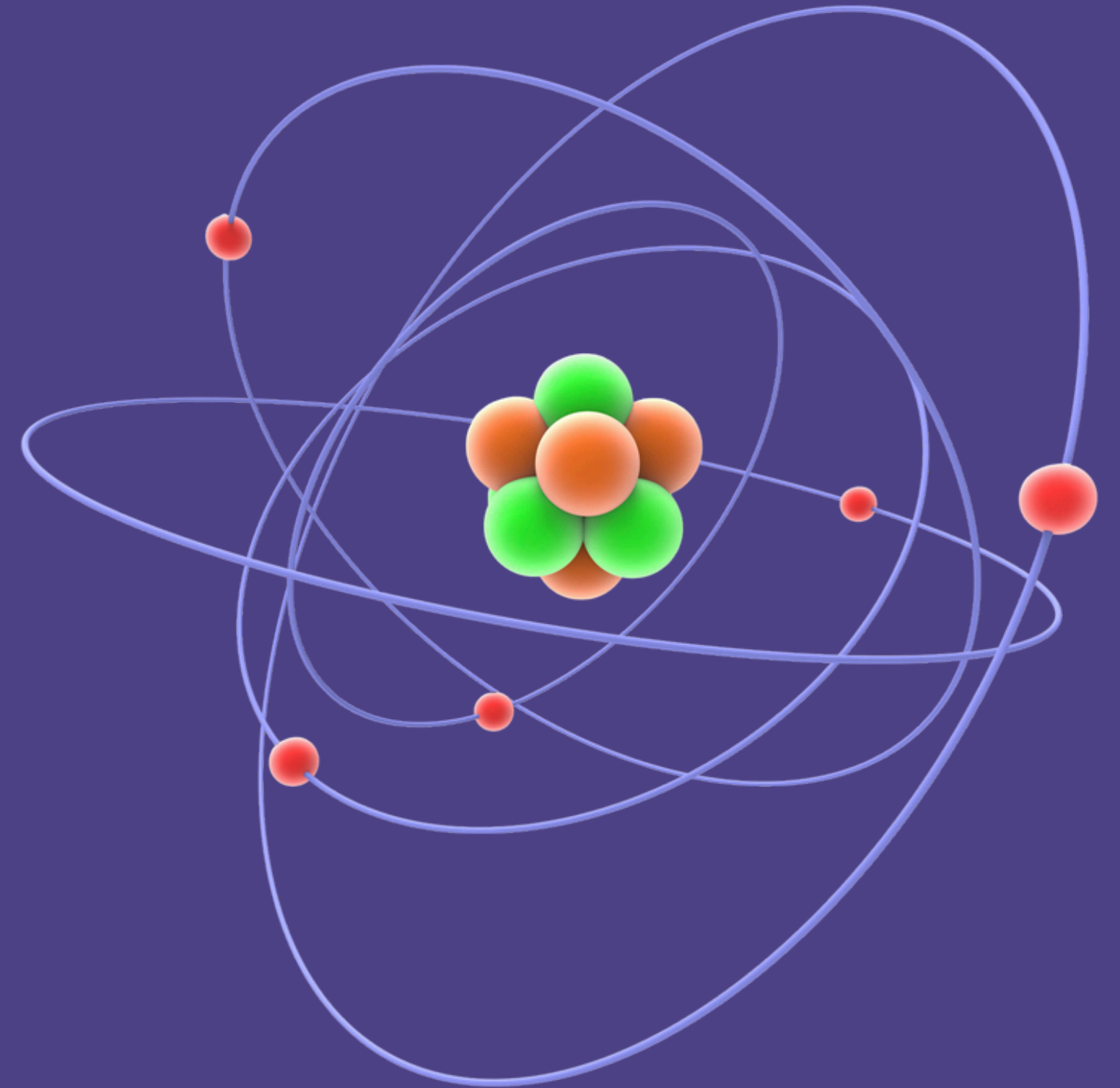
Magnetic domains lined
up and creating their own
magnetic field



THE SCIENCE OF ELECTRO- MAGNETISM

Electricity & Magnetism

- Electrons make magnetism work
 - Spin of electrons
- Electrons make electricity work
 - Movement of electrons



Electromagnetism

- The two are so closely related
 - Where there is electricity, there is a magnetic field
 - When electrons flow, they line up (Ørsted)

Electromagnetism

- The two are so closely related
 - Where there is electricity, there is a magnetic field
 - When electrons flow, they line up (Ørsted)
- Where there is a magnetic field, electricity can be created (Faraday)
 - Magnetic flux can create movement of electrons

ELECTROMAGNETISM

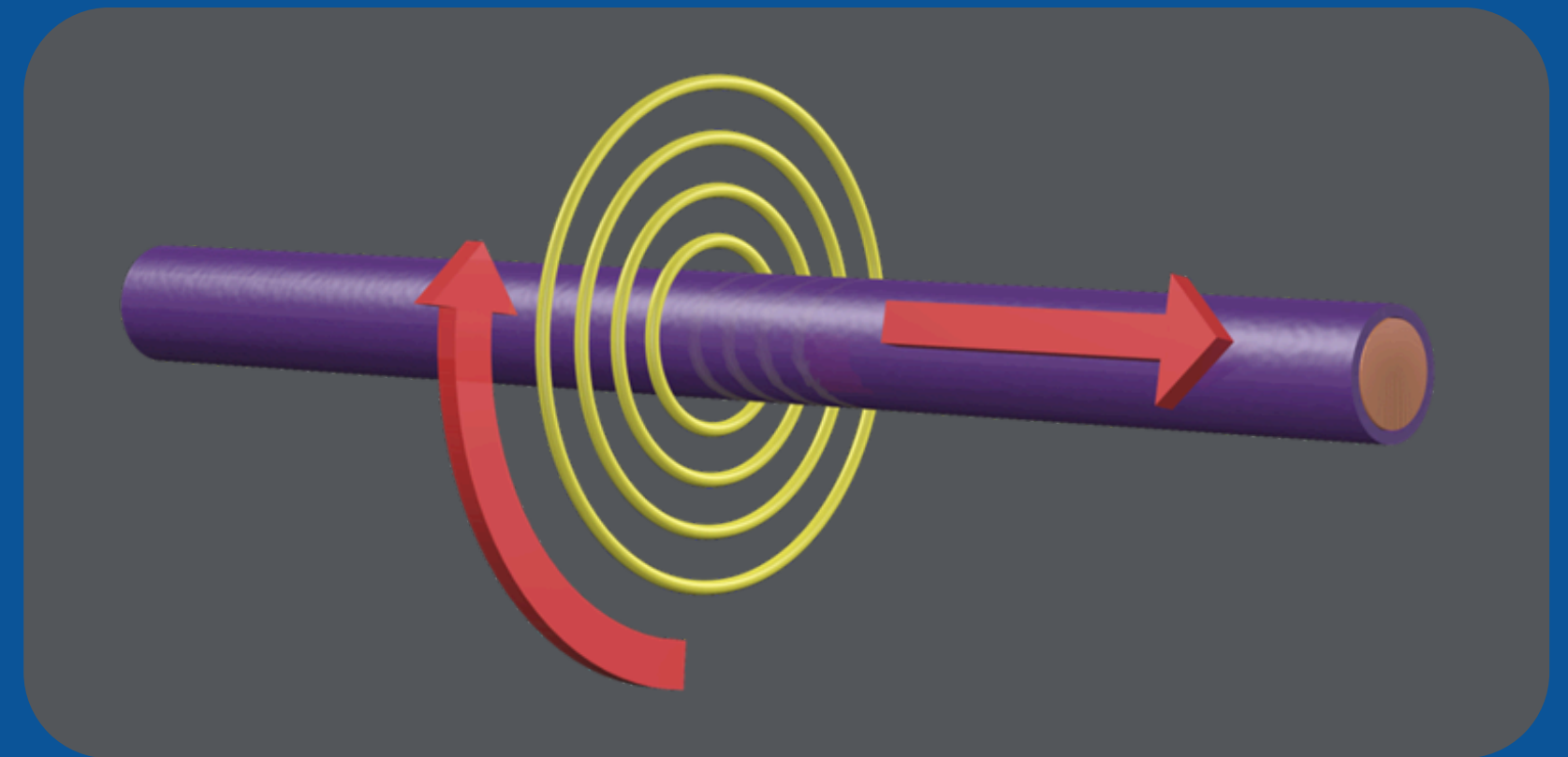
- Electricity is the flow of electrons
 - Electrons flow in same direction

ELECTROMAGNETISM

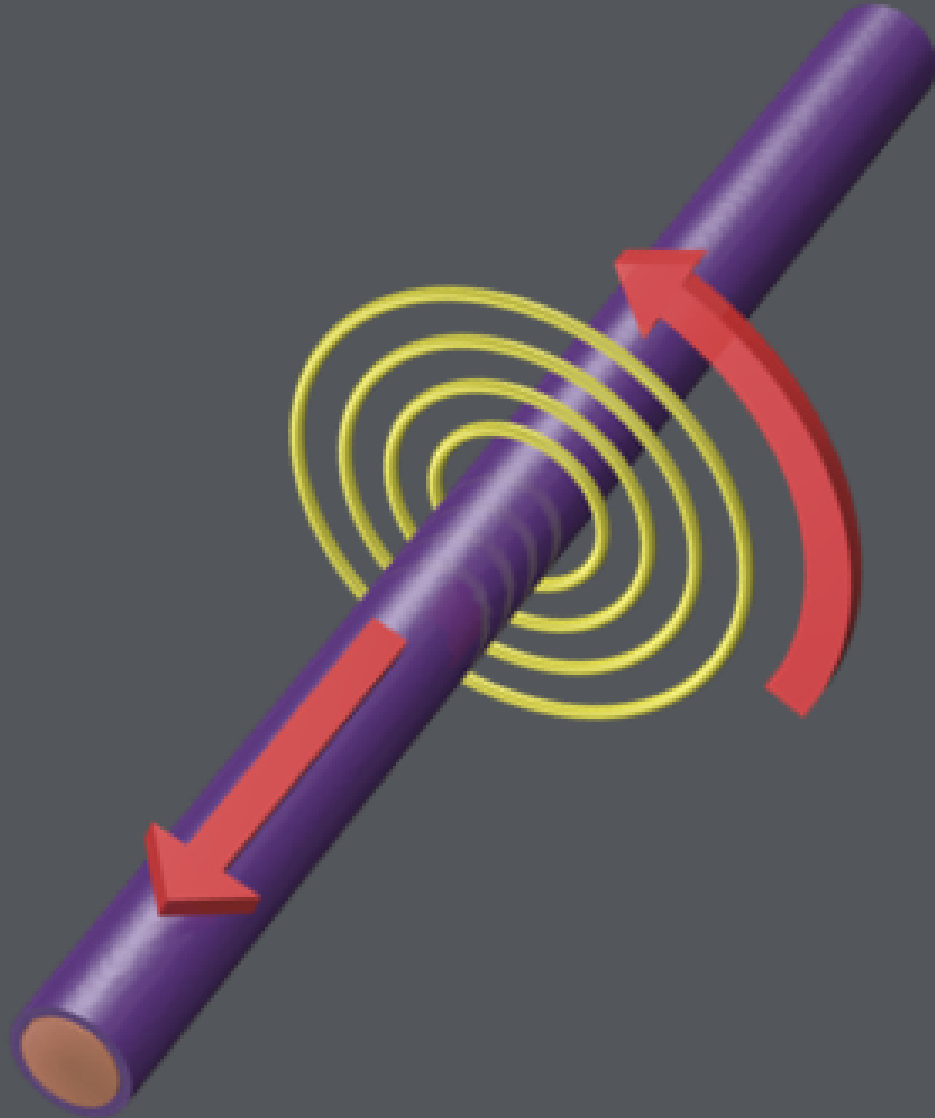
- Electricity is the flow of electrons
 - Electrons flow in same direction
- This alignment of electrons creates a magnetic field around the conductor
 - Similar to electrons lining up in a permanent magnet
 - Every wire carrying electricity has a weak magnetic field around it

ELECTROMAGNETISM

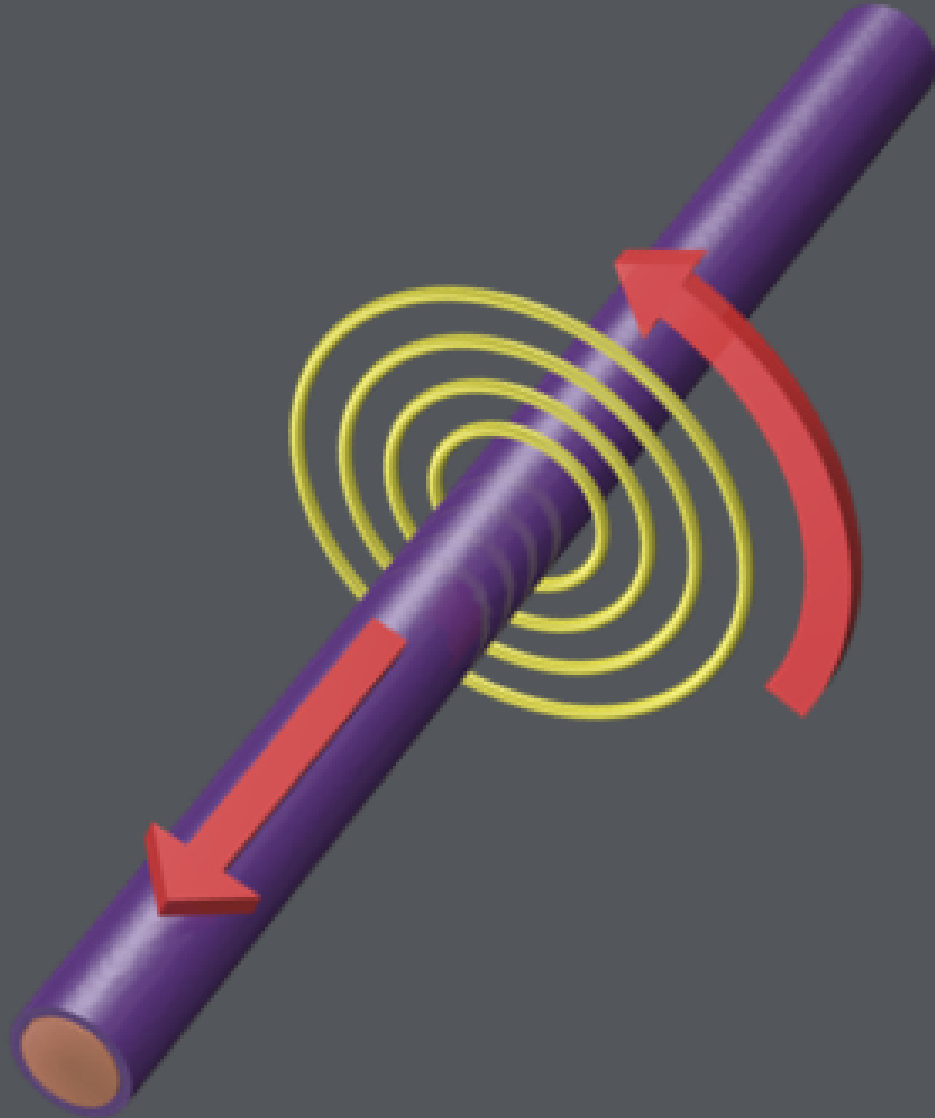
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MAKING MAGNETISM

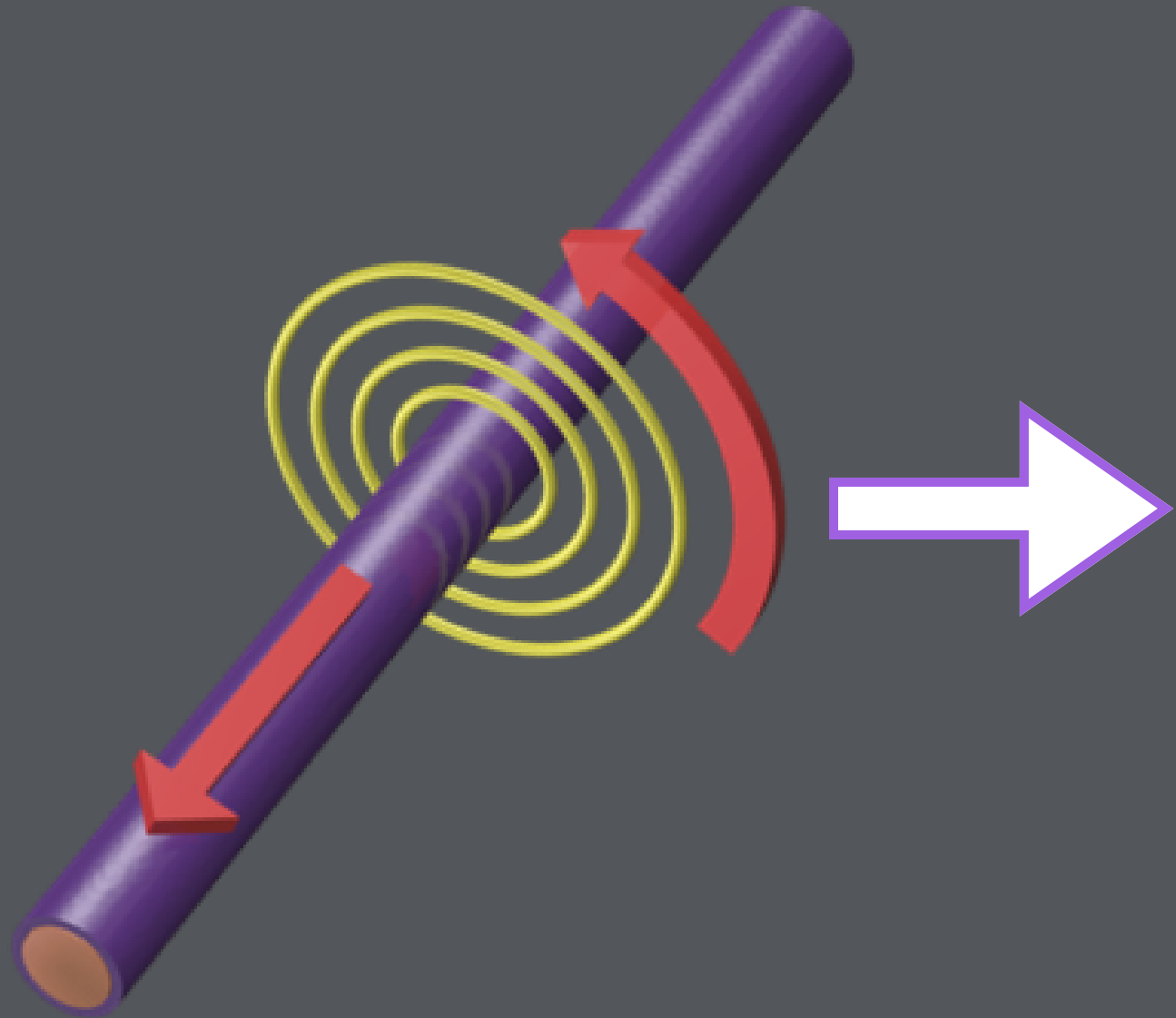


MAKING MAGNETISM



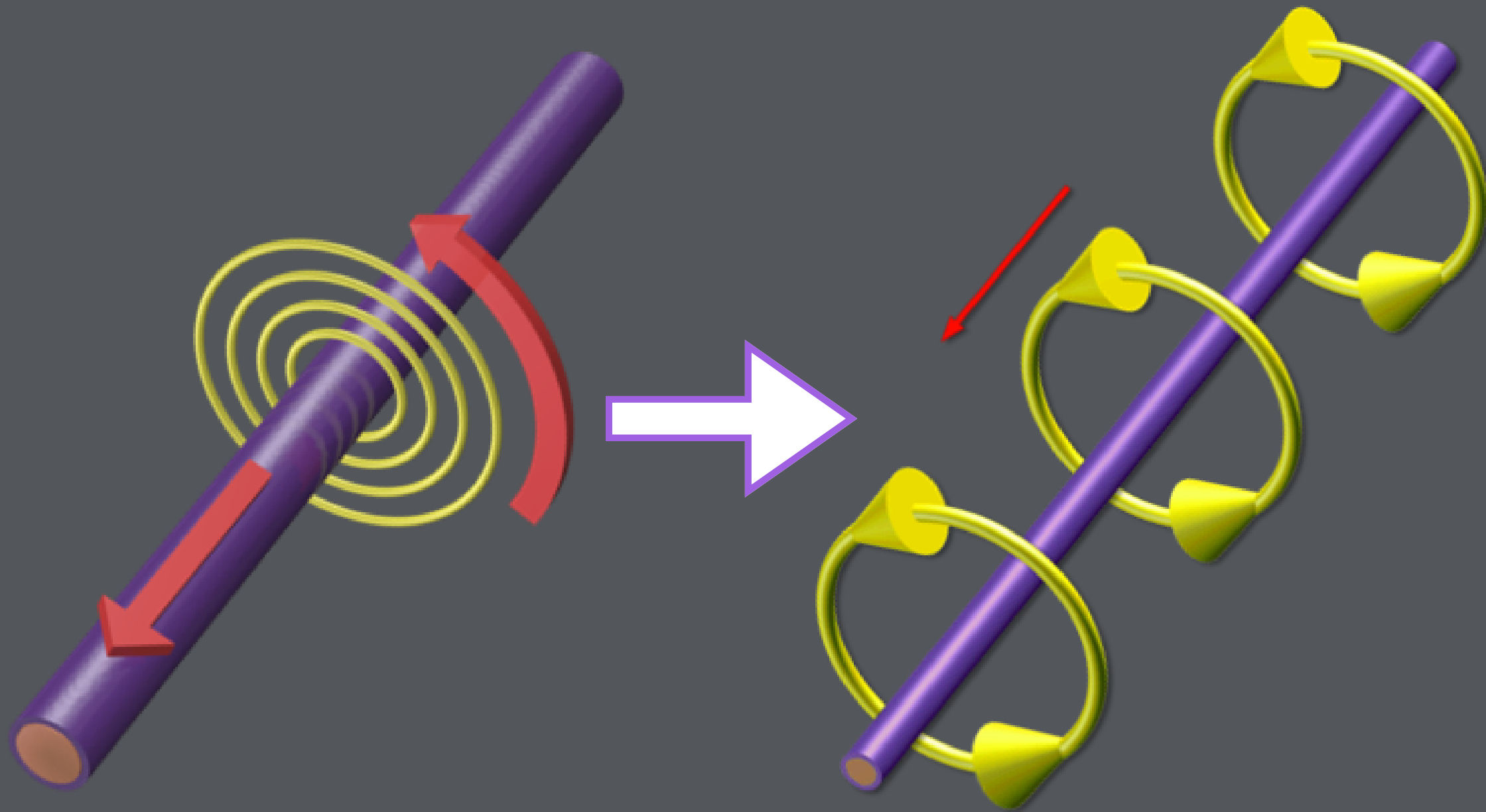
The magnetic field
exists at all points
along the wire

MAKING MAGNETISM



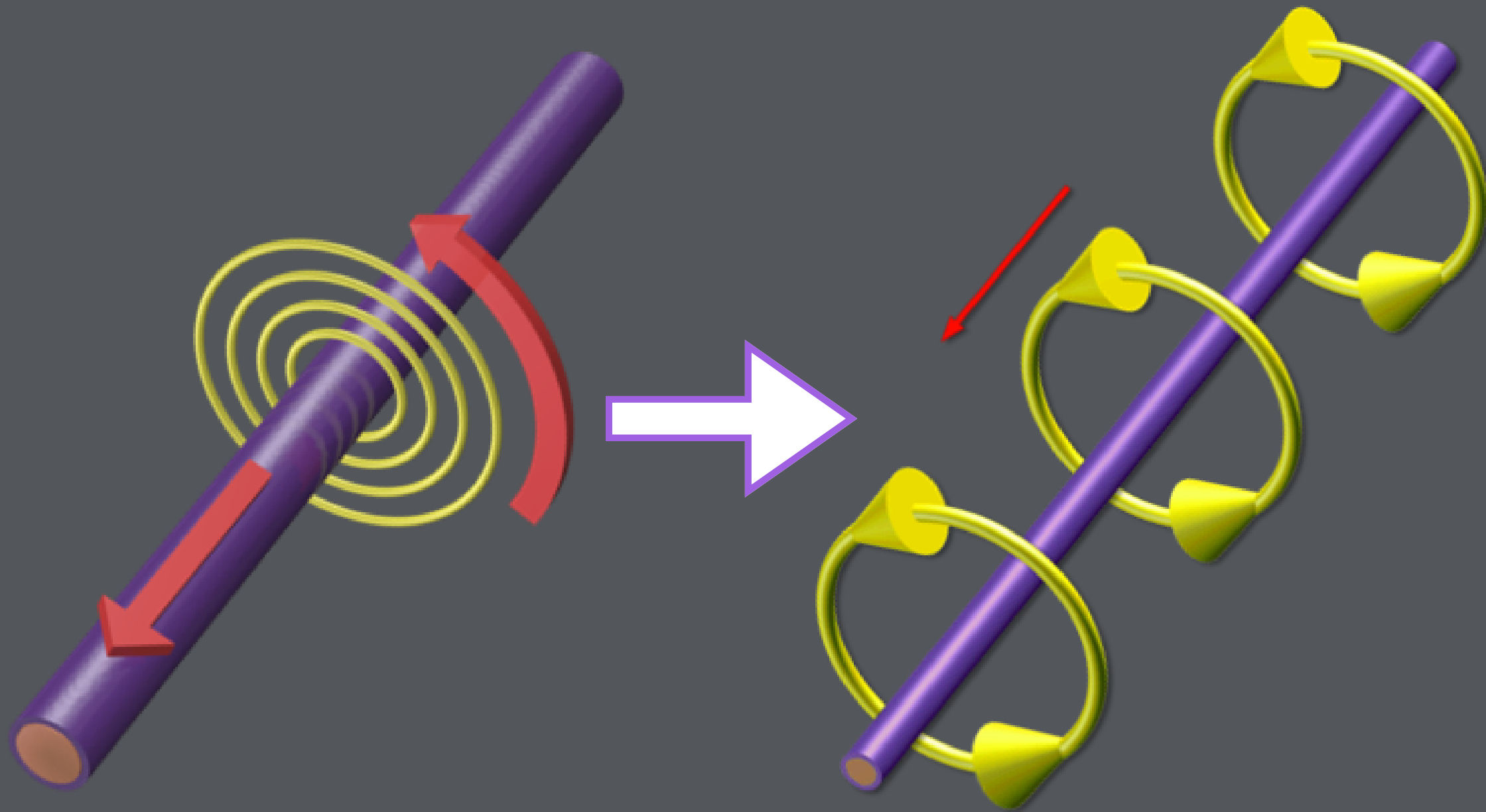
The magnetic field
exists at all points
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MAKING MAGNETISM



The magnetic field
exists at all points
along the wire

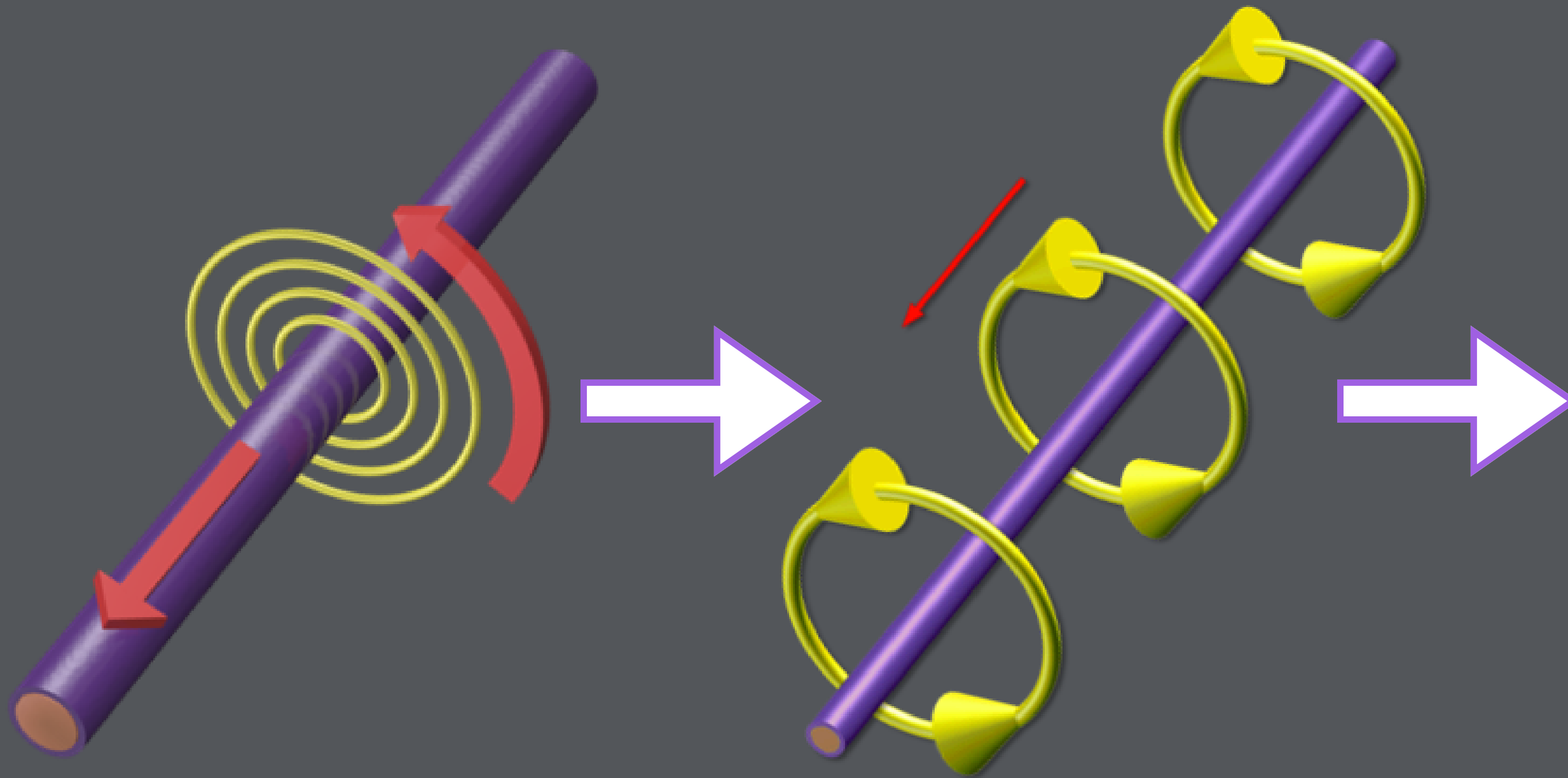
MAKING MAGNETISM



The magnetic field
exists at all points
along the wire

Coiling the wire
concentrates the magnetic
field inside the coil

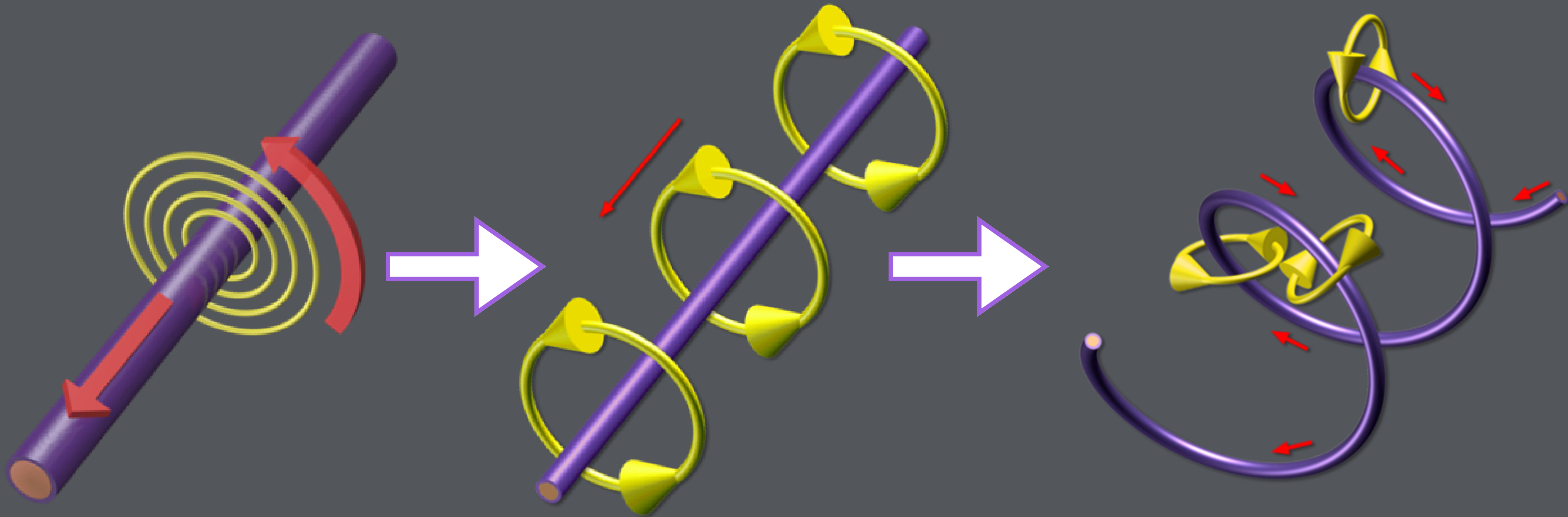
MAKING MAGNETISM



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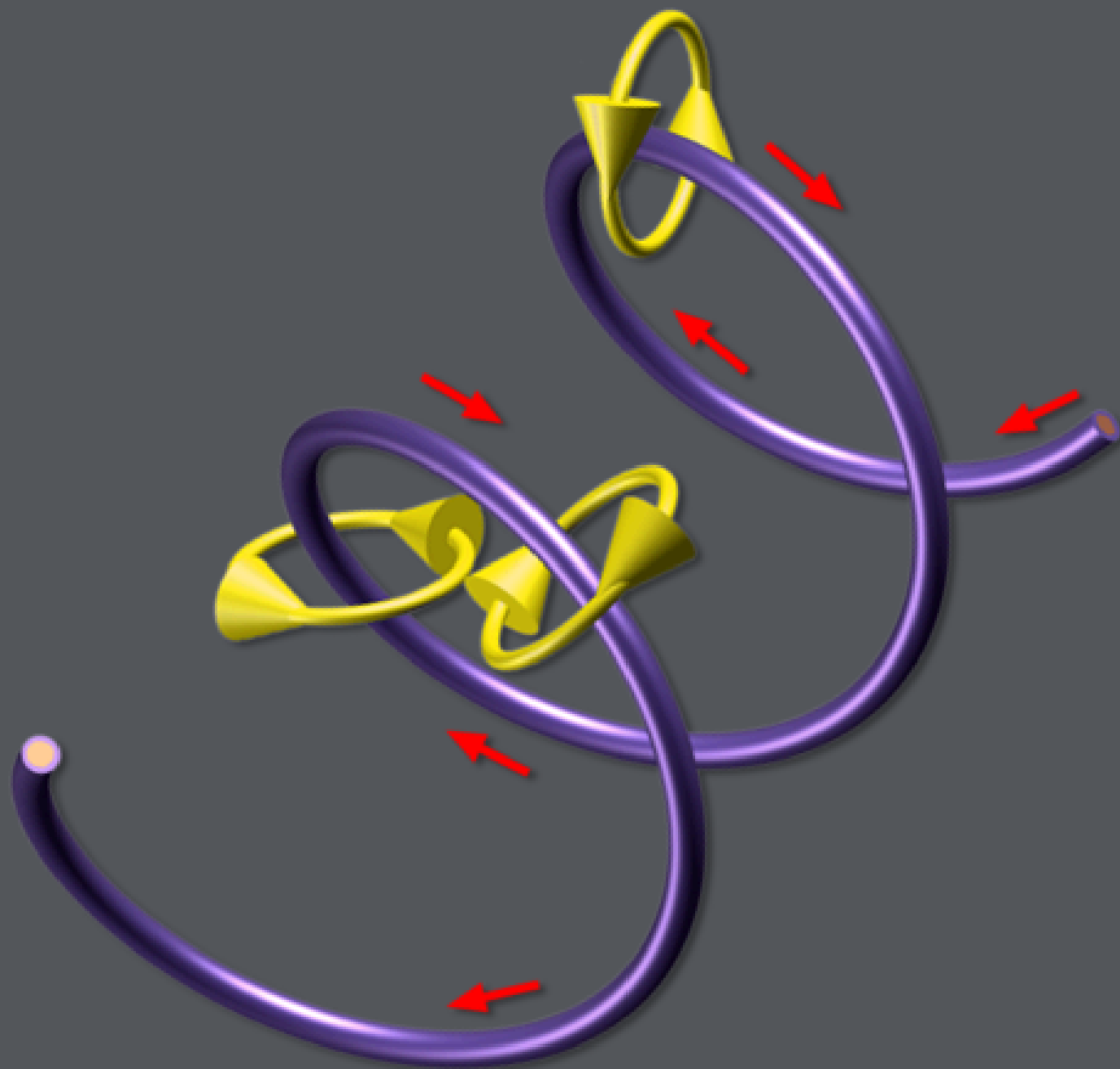
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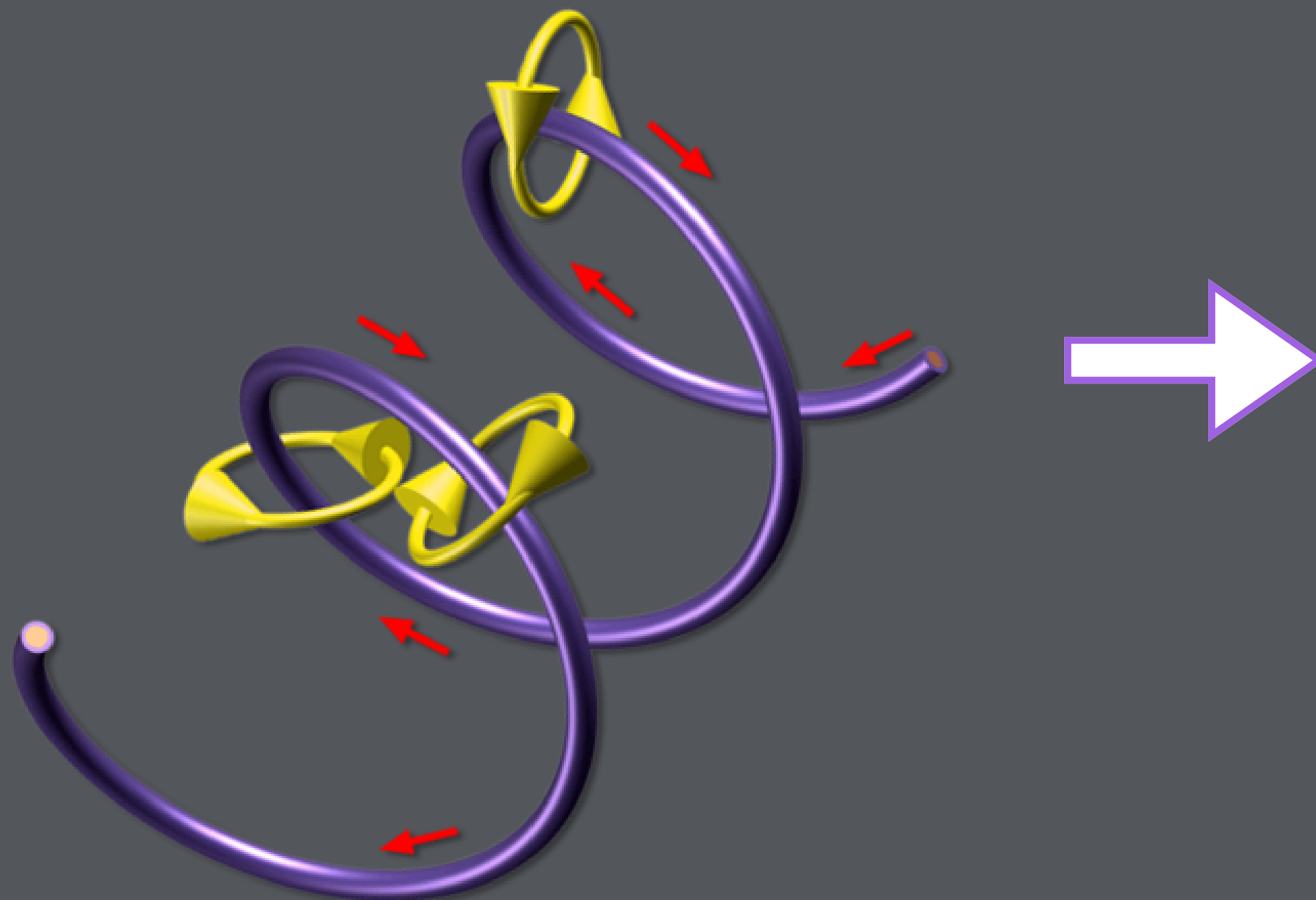
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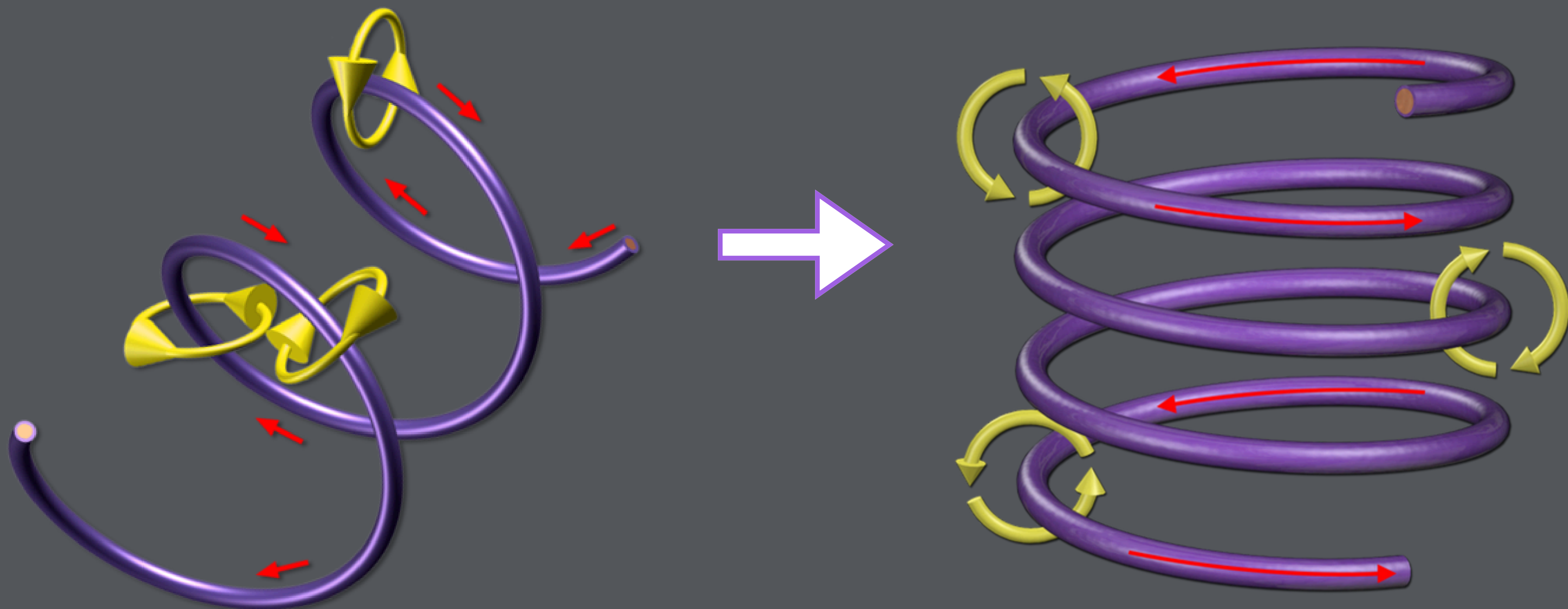
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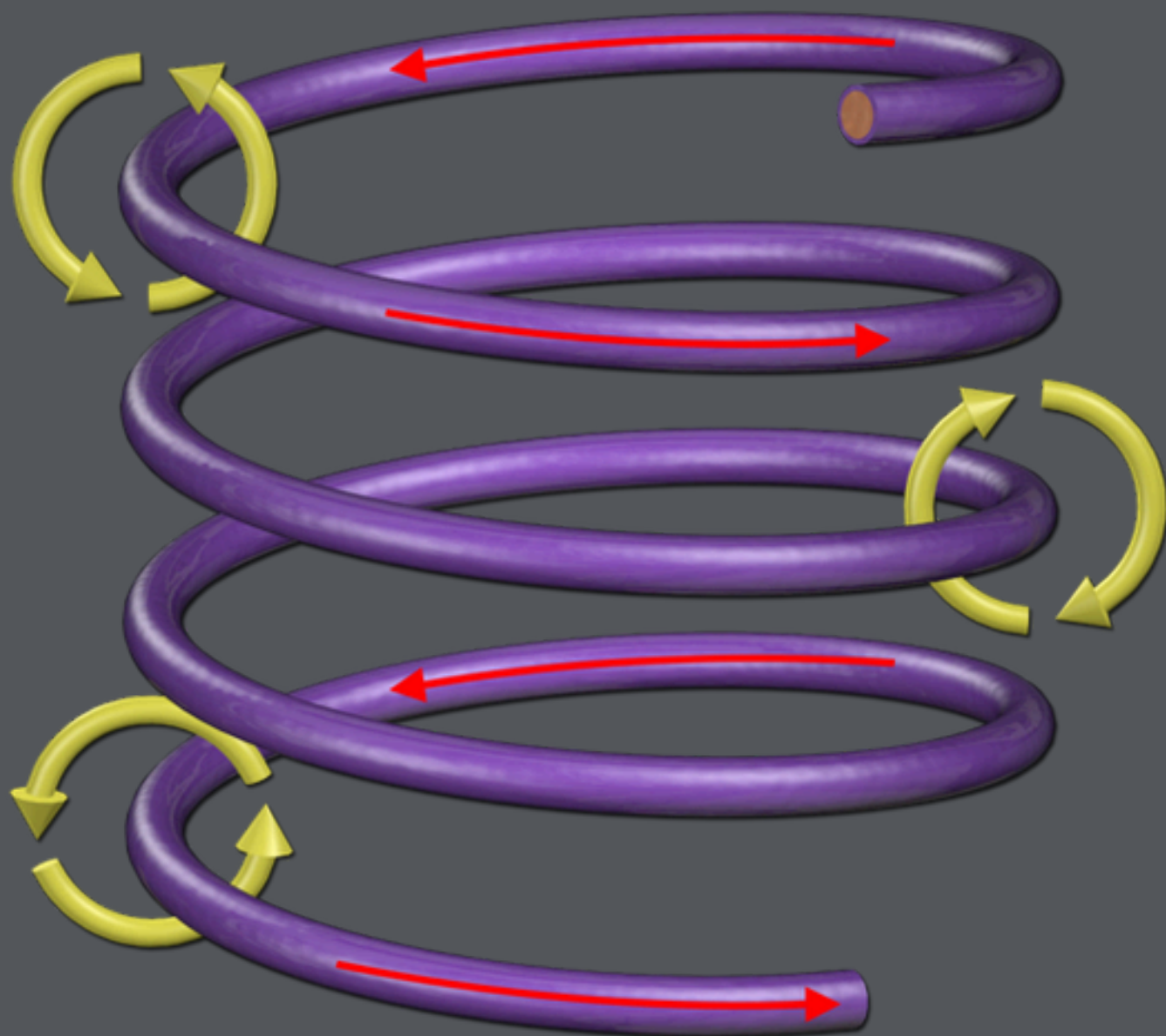
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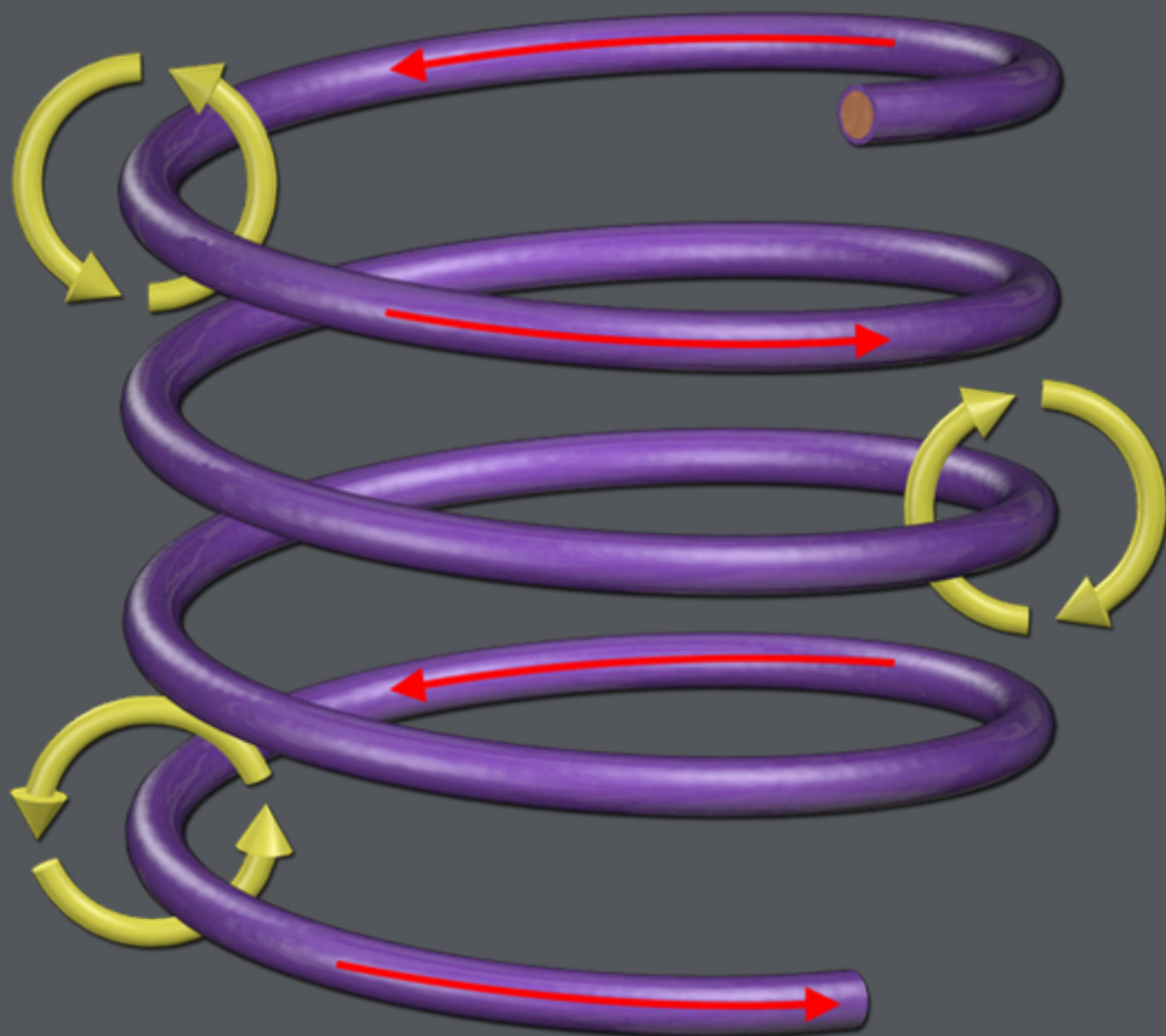
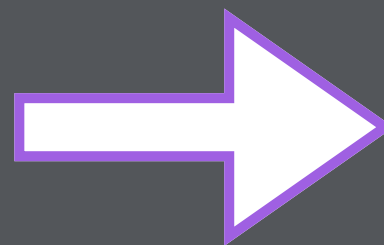
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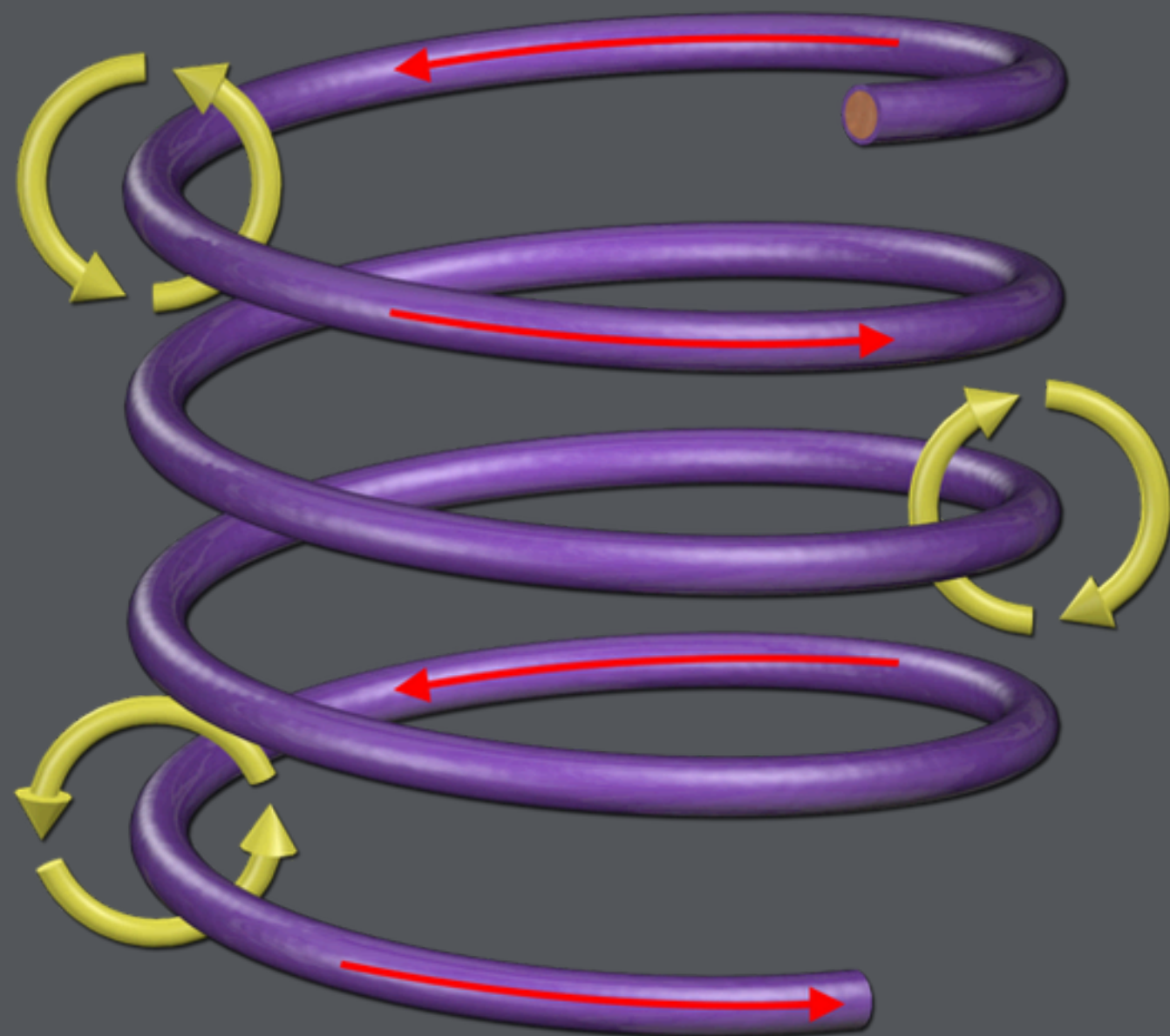
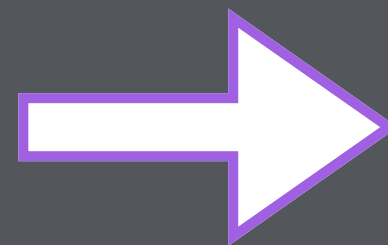
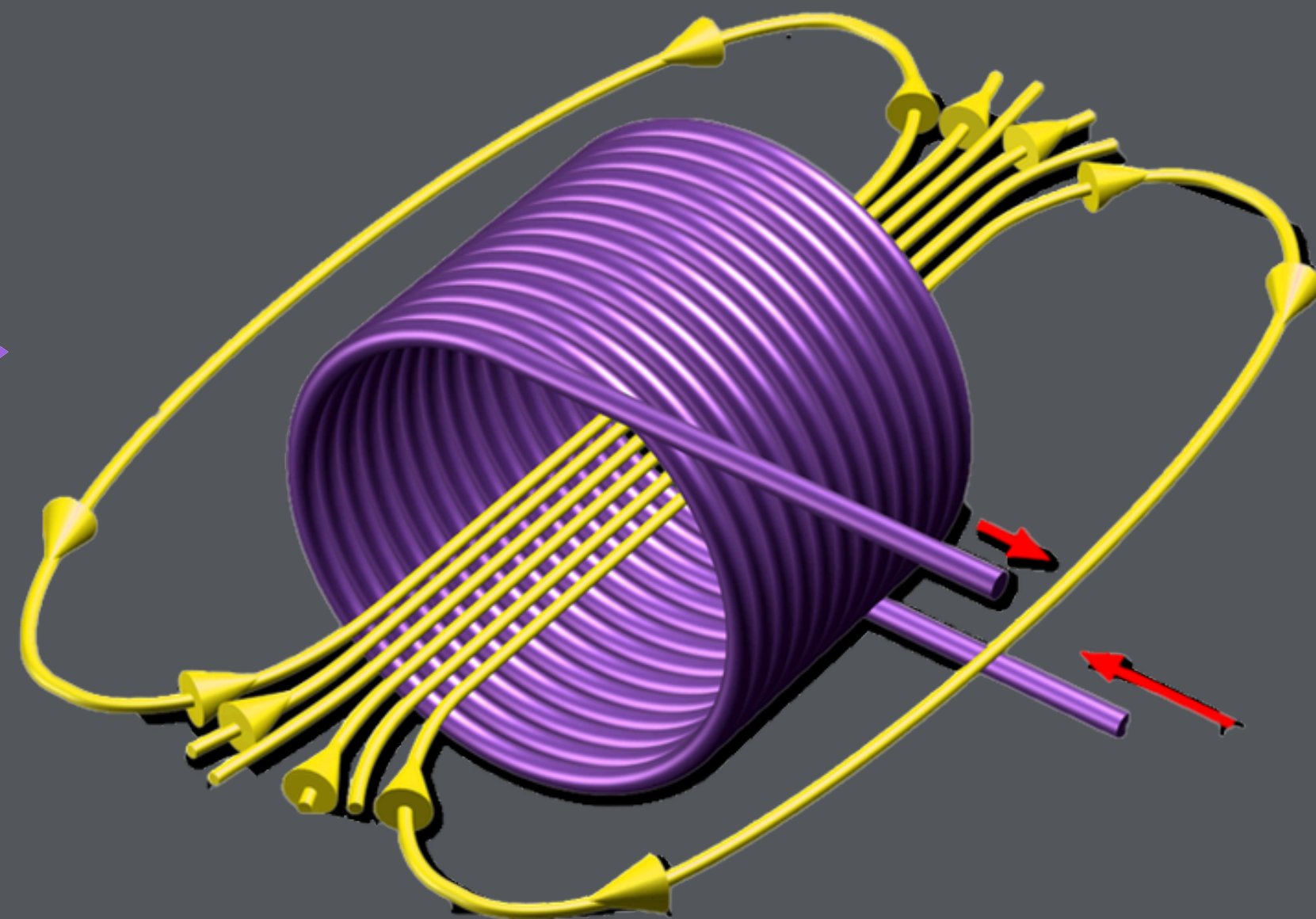
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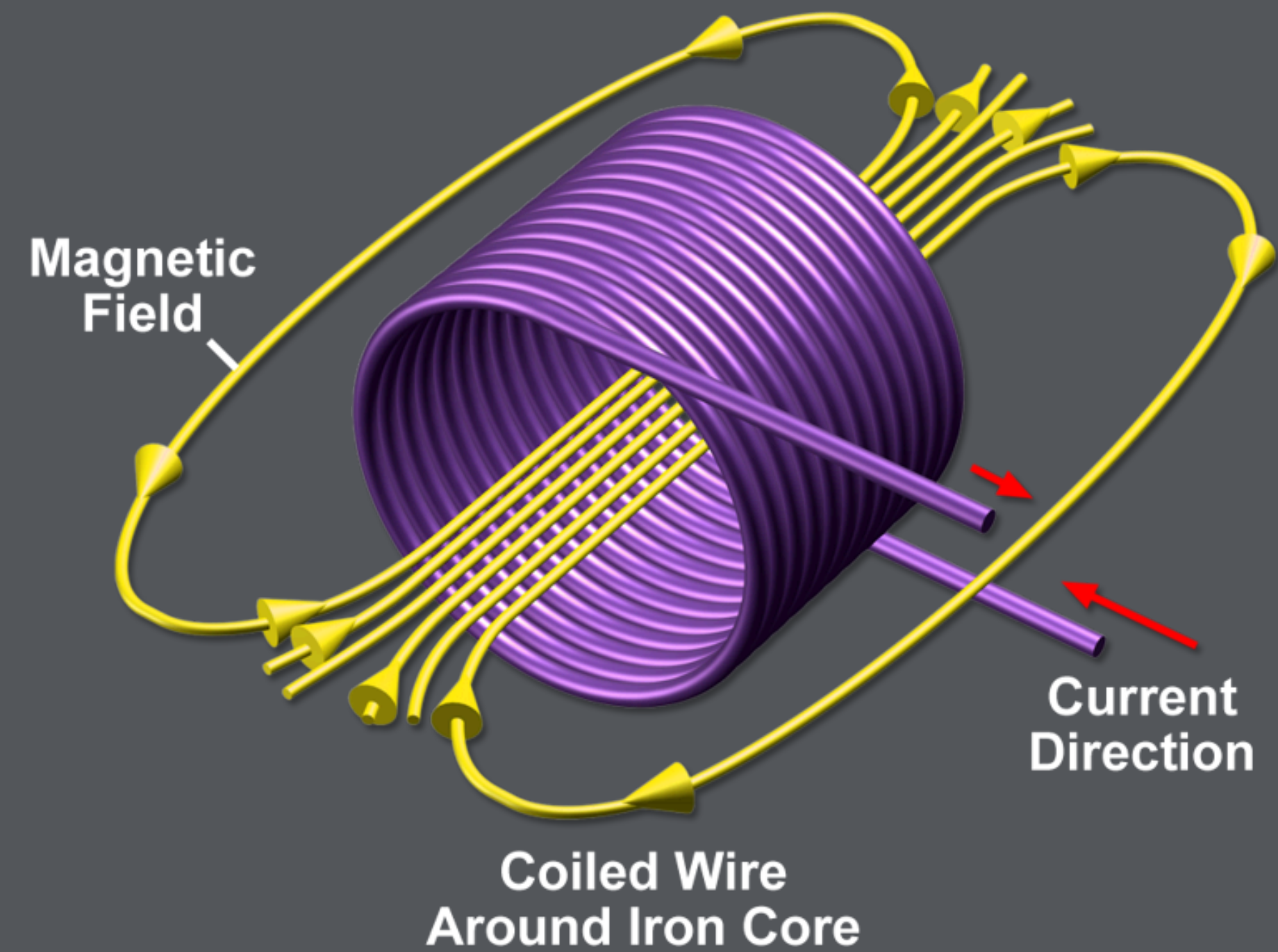
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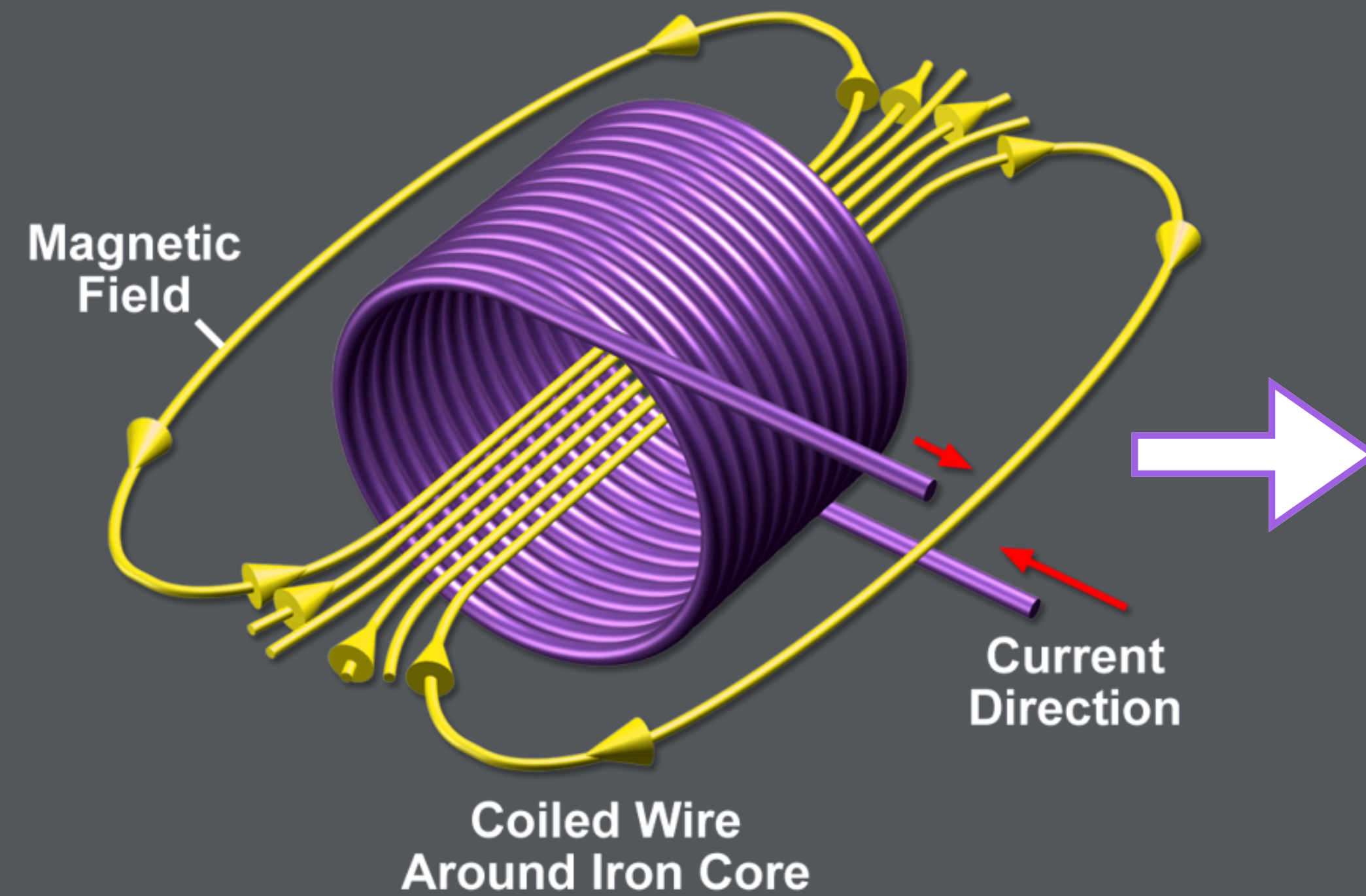
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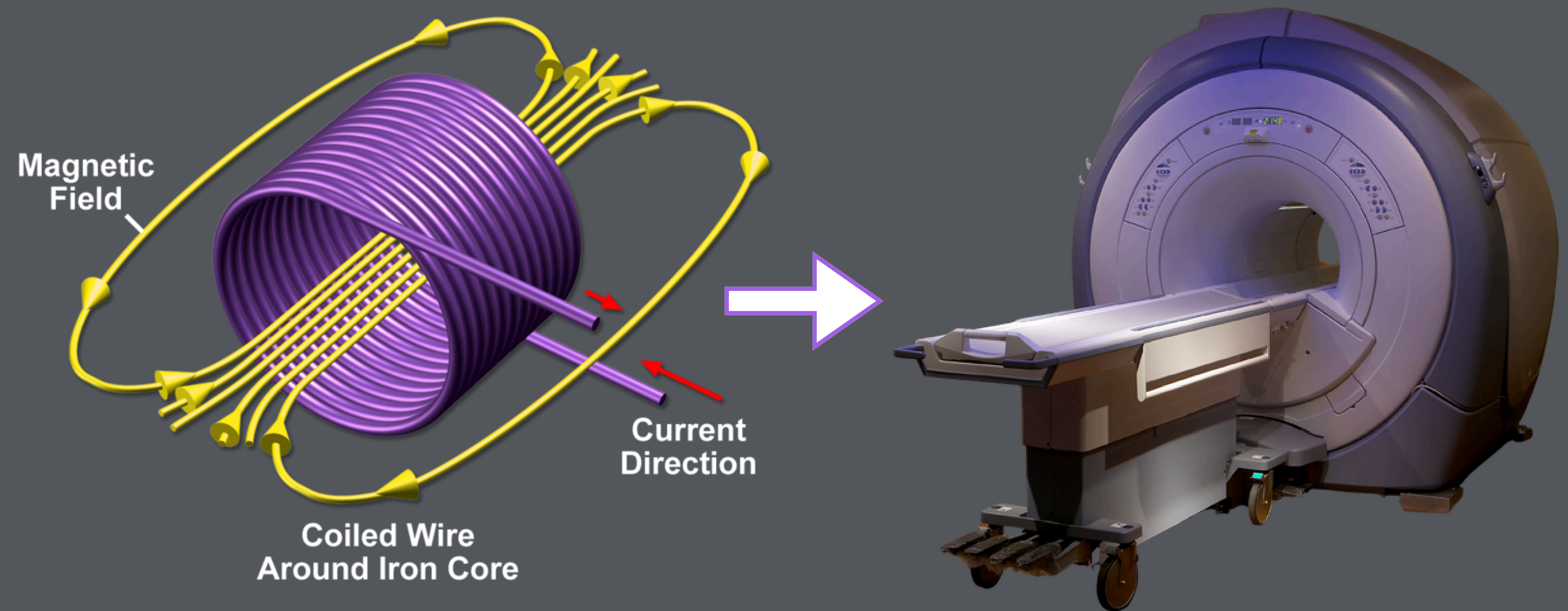
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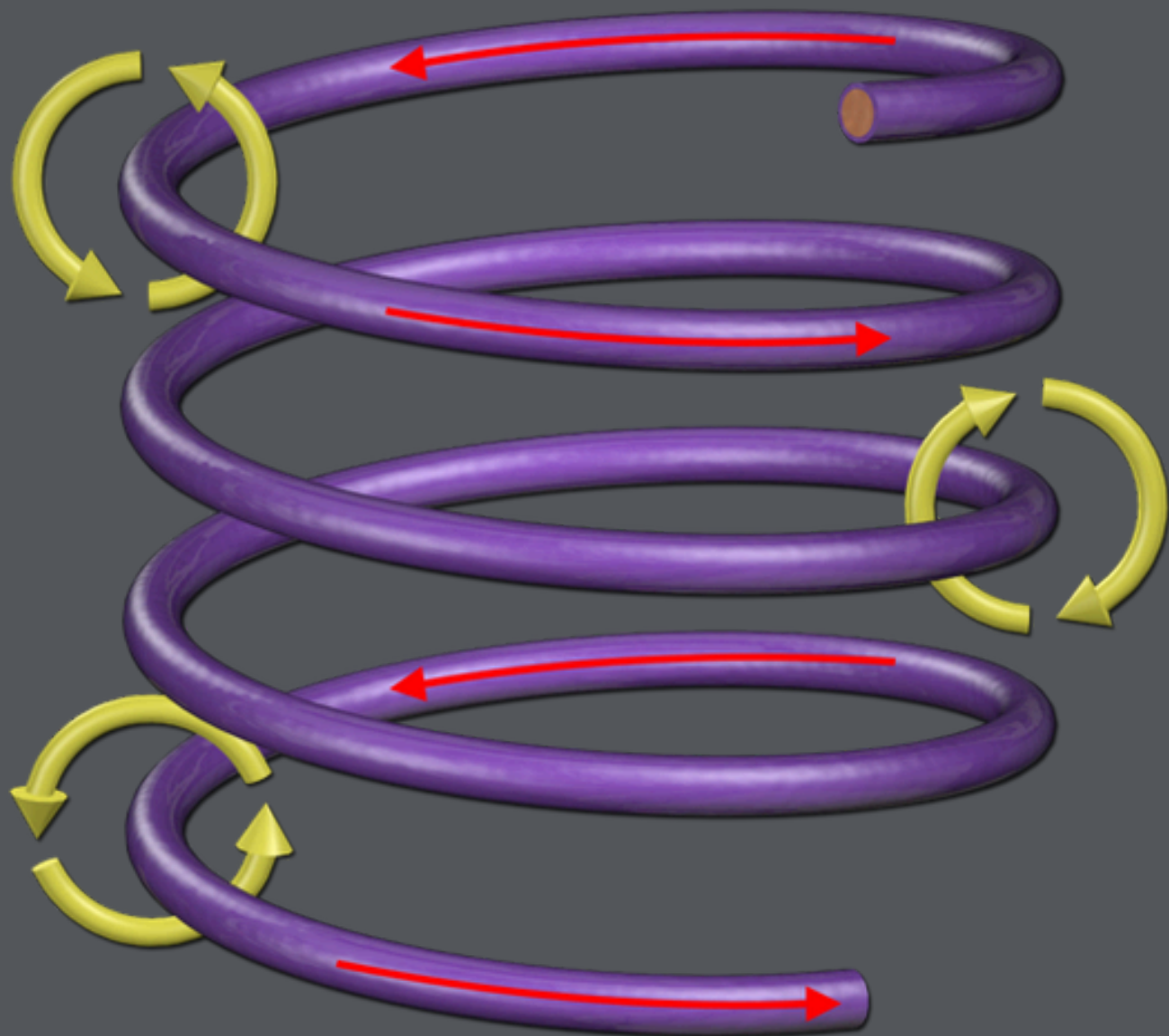
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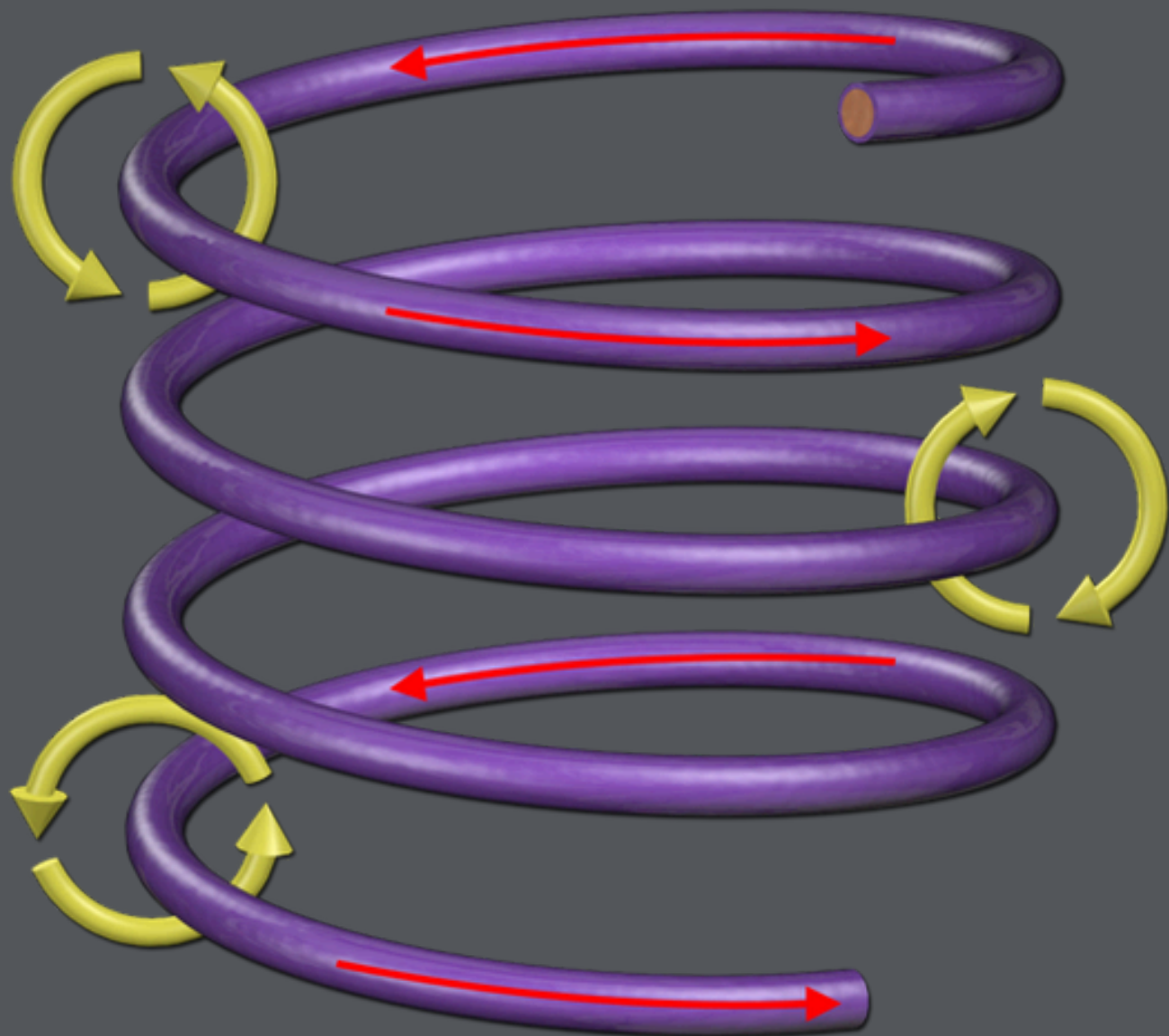
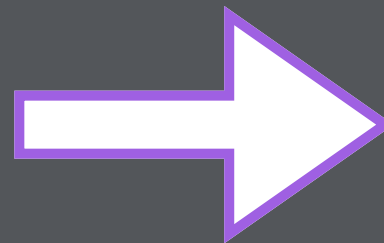
MAKING MAGNETISM



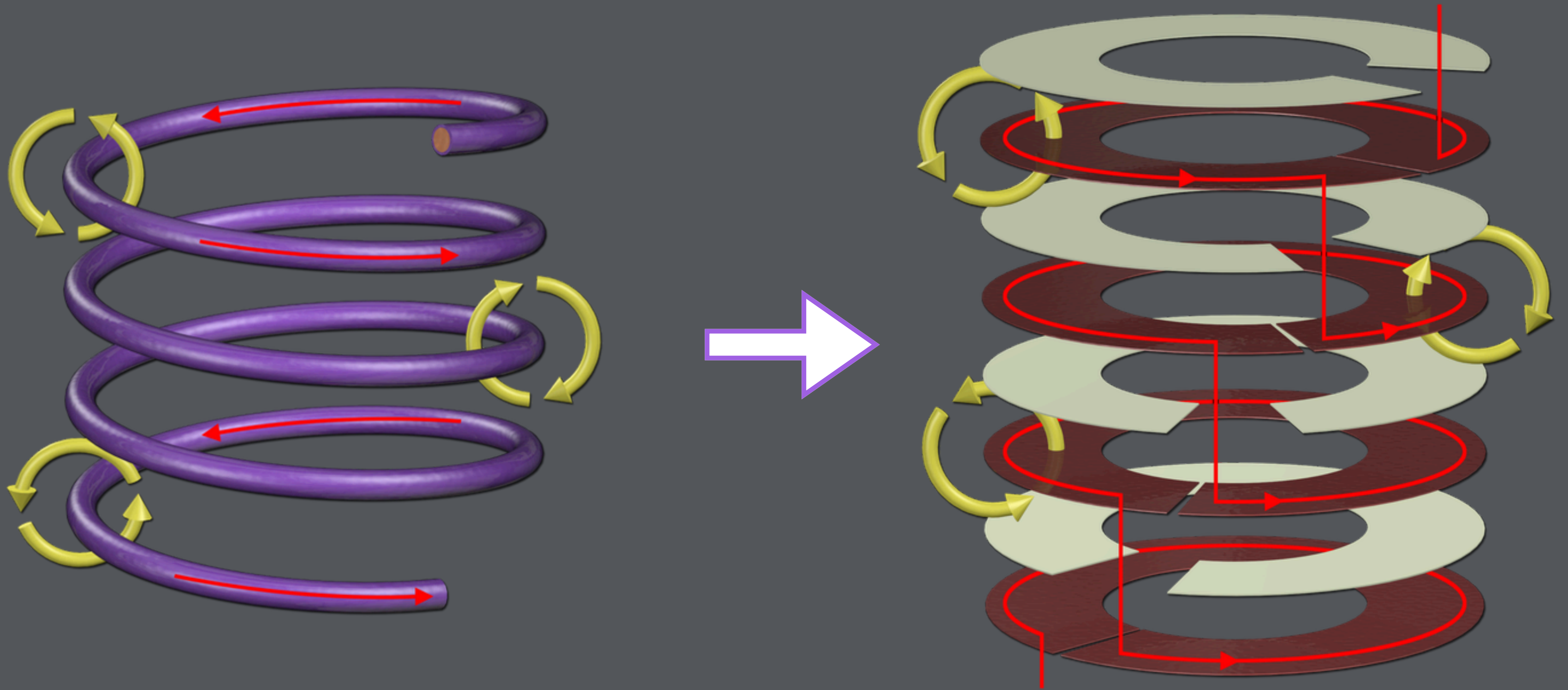
MAKING MAGNETISM



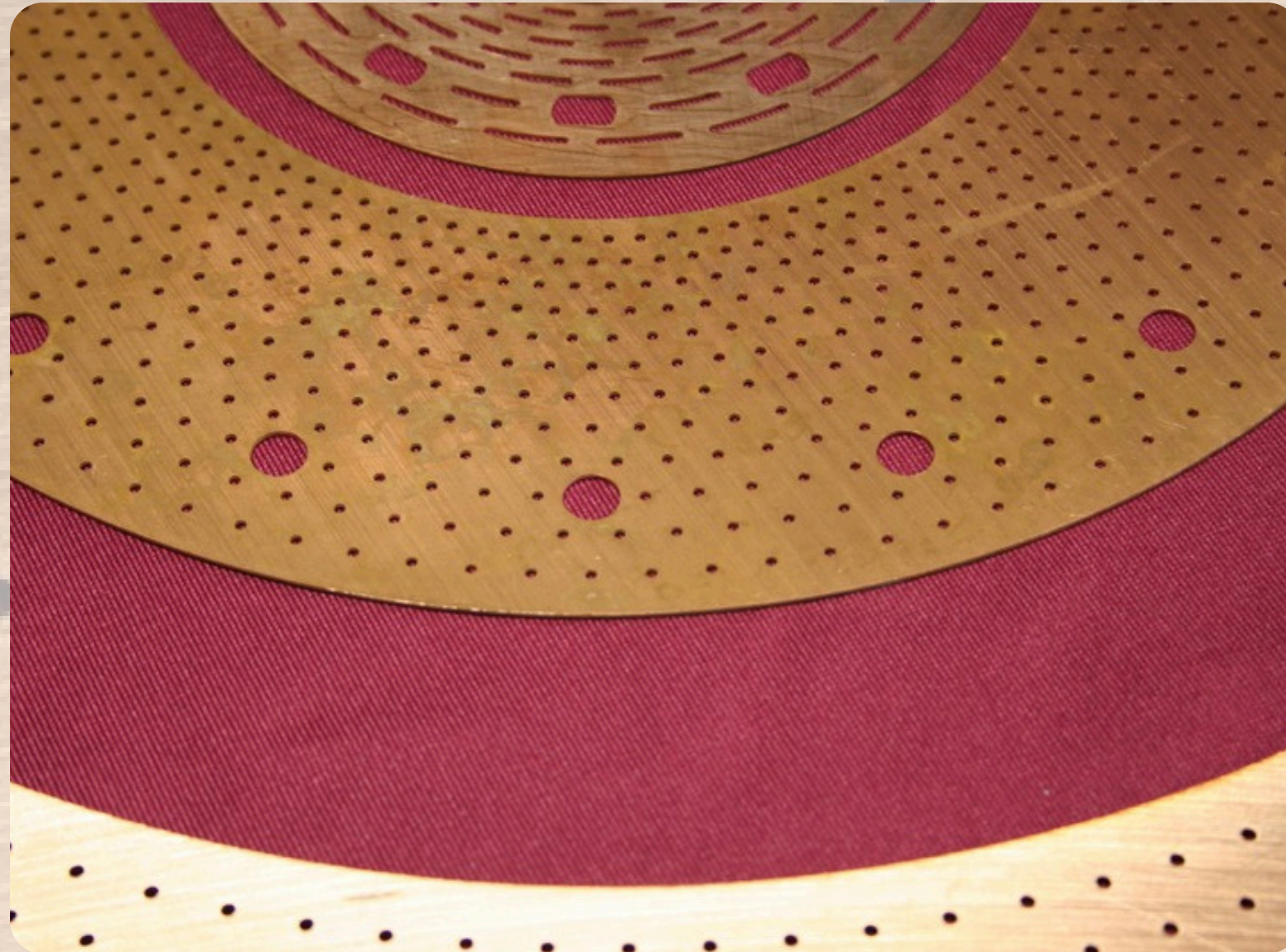
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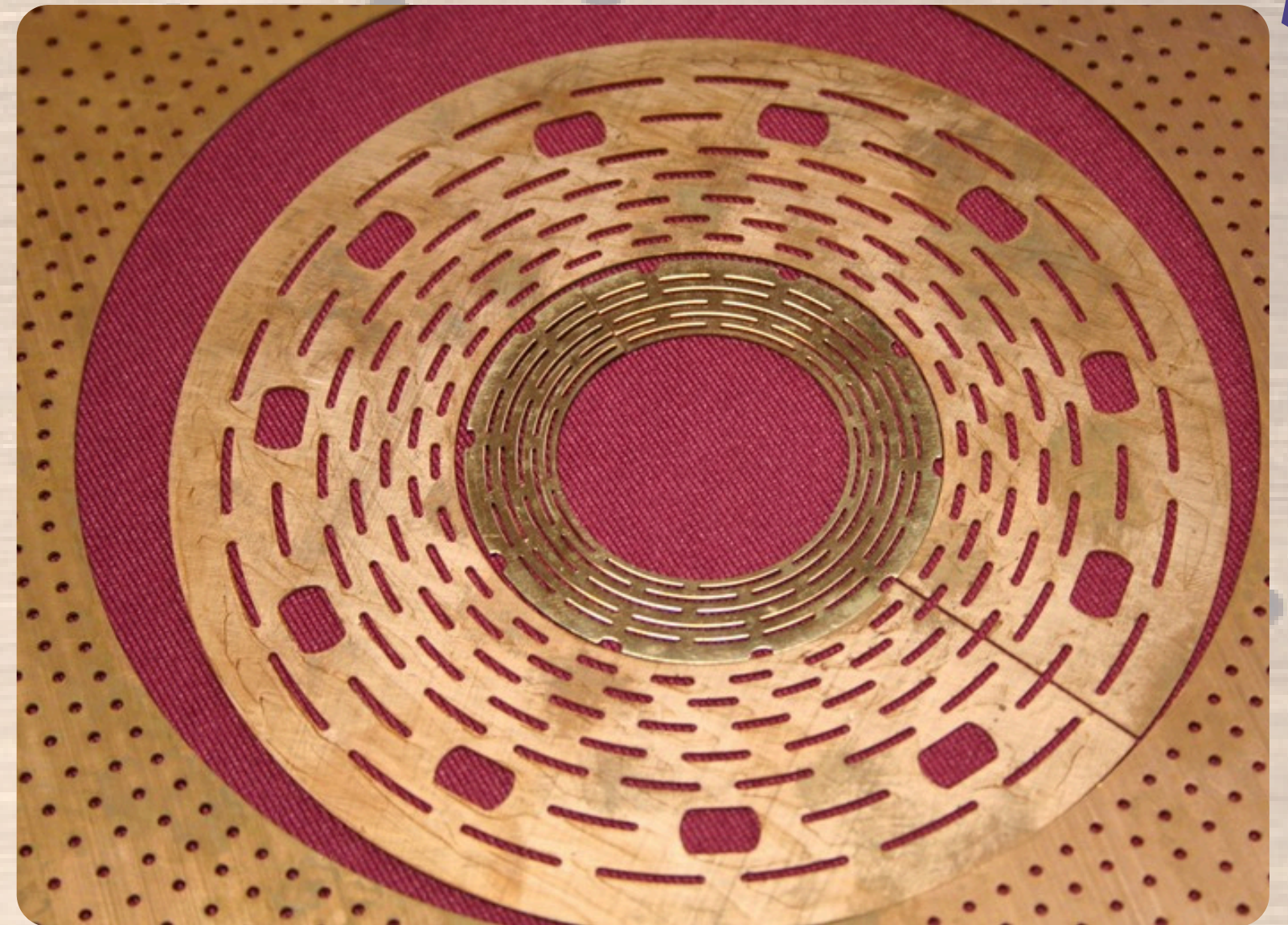
MAKING MAGNETISM



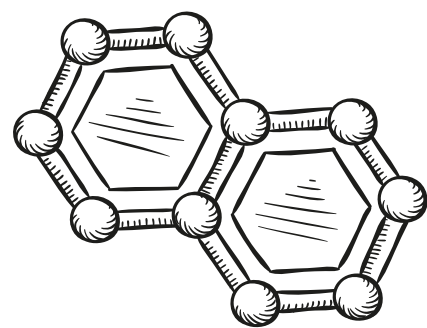
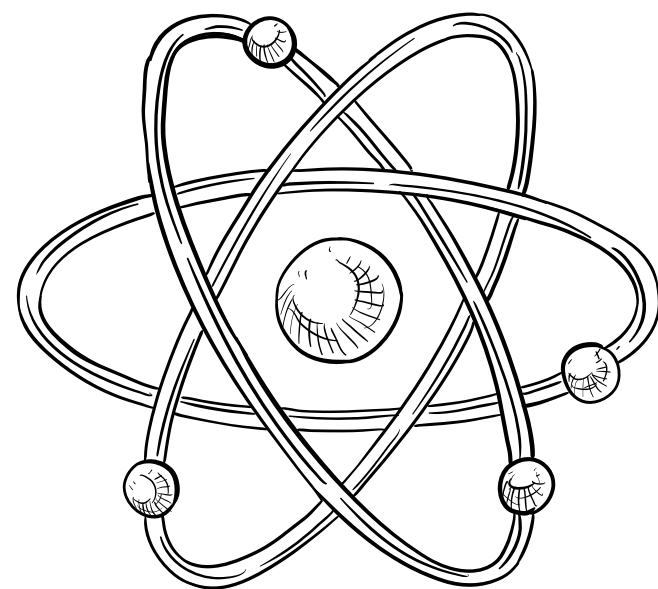
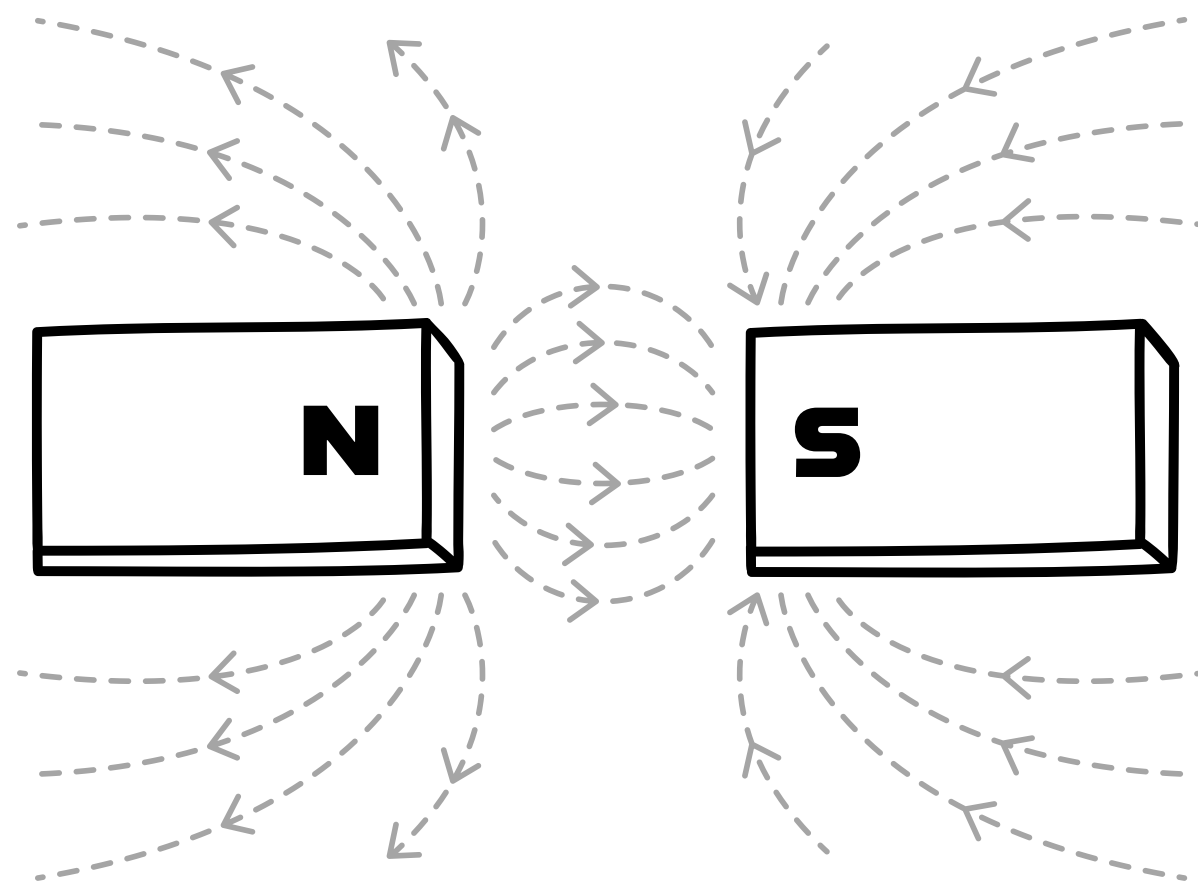
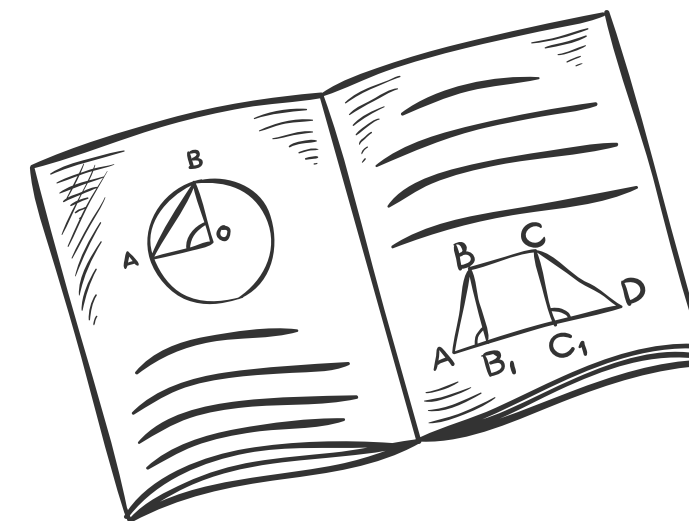
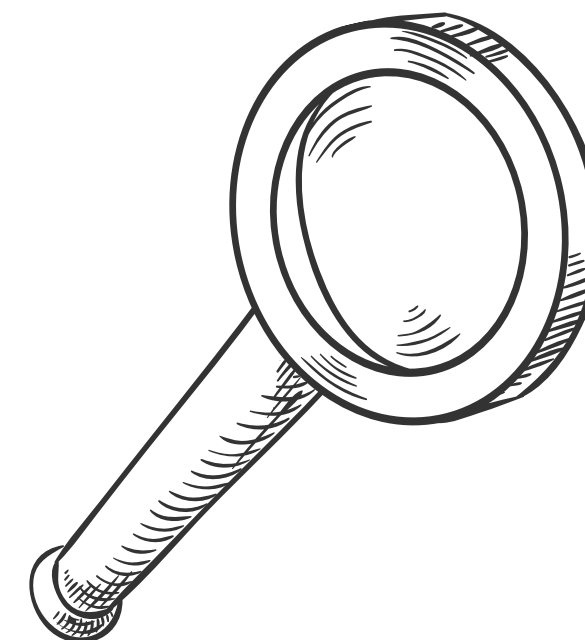
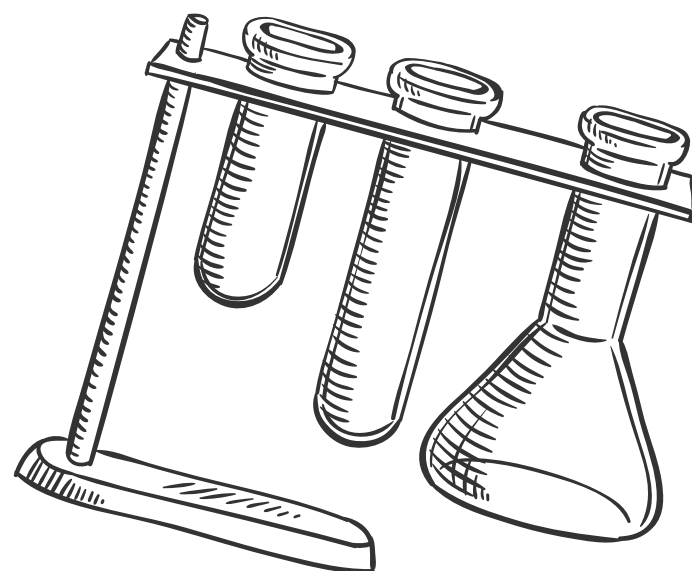
FLORIDA BITTER MAGNETS



- The MagLab builds the world's highest-field resistive magnets using Florida Bitter plates.
- Based on Francis Bitter's design, the MagLab increased efficiency by 40% by optimizing cooling-hole shape
- Florida Bitter magnets are built from stacked copper and insulating plates & carry about 40,000 amps.



- Cooling water flows through the magnets at speeds of up to 45 mph to prevent overheating; without cooling, the magnets would melt in fractions of a second.
- Four of the five largest magnet labs in the world now use Florida Bitter magnet technology.



ELECTRO- MAGNETISM IN YOUR CLASS



**COW
* MAGNETS ***

Five small
magnets



One long
magnet



Money & Magnetism

Your money is magnetism
(Not what you think though)



Money & Magnetism

Money is magnetic:

Coins are copper-nickel alloy
(not magnetic)

Pennies are copper-plated
zinc (also not magnetic)

Dollars are printed with iron-
rich ink (magnetic!)

Foreign Coins

Canadian, British, Brazilian,
Mexican (some)...





Magnetism in our Food

Pulling Iron



- Iron in cereal
 - NIB Magnet is a must
 - Total brand
 - Baby cookies (high in iron)

Pulling Iron



- Iron in cereal
 - NIB Magnet is a must
 - Total brand
 - Baby cookies (high in iron)

Pulling Iron



- The Hook:
 - Blend a \$1 bill
 - Use a NIB magnet
 - Pull out the iron

Permanent & Temporary Magnets



- No rubbing necessary
 - Magnetism happens almost instantly

Permanent & Temporary Magnets



- No rubbing necessary
 - Magnetism happens almost instantly
- They are magnets
 - North and South
 - Attract and Repel

Permanent & Temporary Magnets



- No rubbing necessary
 - Magnetism happens almost instantly
- They are magnets
 - North and South
 - Attract and Repel
- Paper Clips remain magnetic
 - Until something tampers with their field
 - Field could last years

• ► MAGNETISM IN THE UNIVERSE

- *Meteors are high in iron content*
- *Burn up in atmosphere*
- *Waves wash them ashore*



• ► MAGNETISM IN THE UNIVERSE

- *Meteors are high in iron content*
- *Burn up in atmosphere*
- *Waves wash them ashore*

- Hold a strong magnet over beach sand
- Iron will attract to the magnet
- Excess sand will cling to the magnet
 - Purify by spreading it on a sheet of paper and passing the magnet over it
- Instant Star Dust



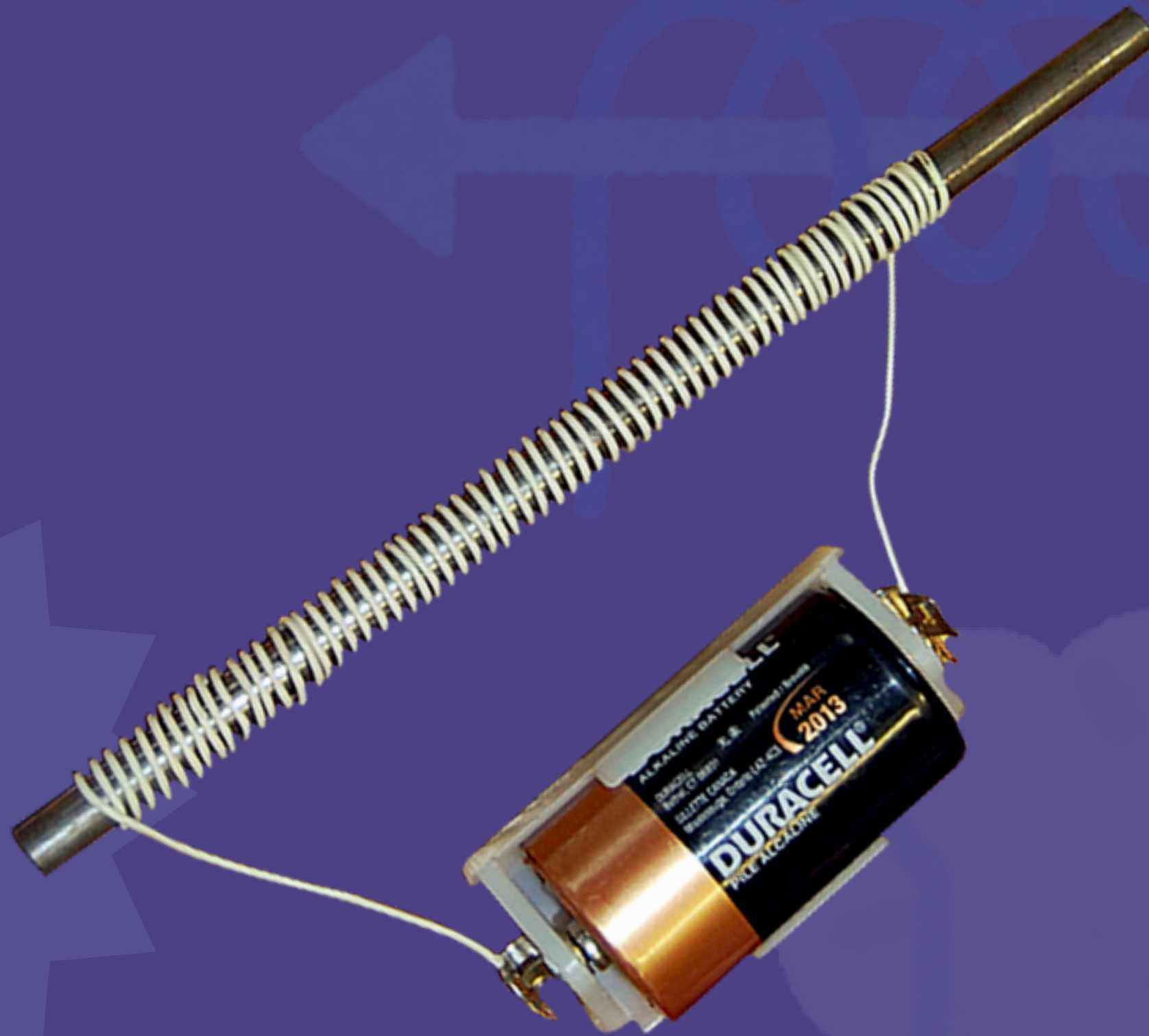
ELECTROMAGNETISM

MATERIALS

- COPPER WIRE
- IRON ROD
- BATTERY

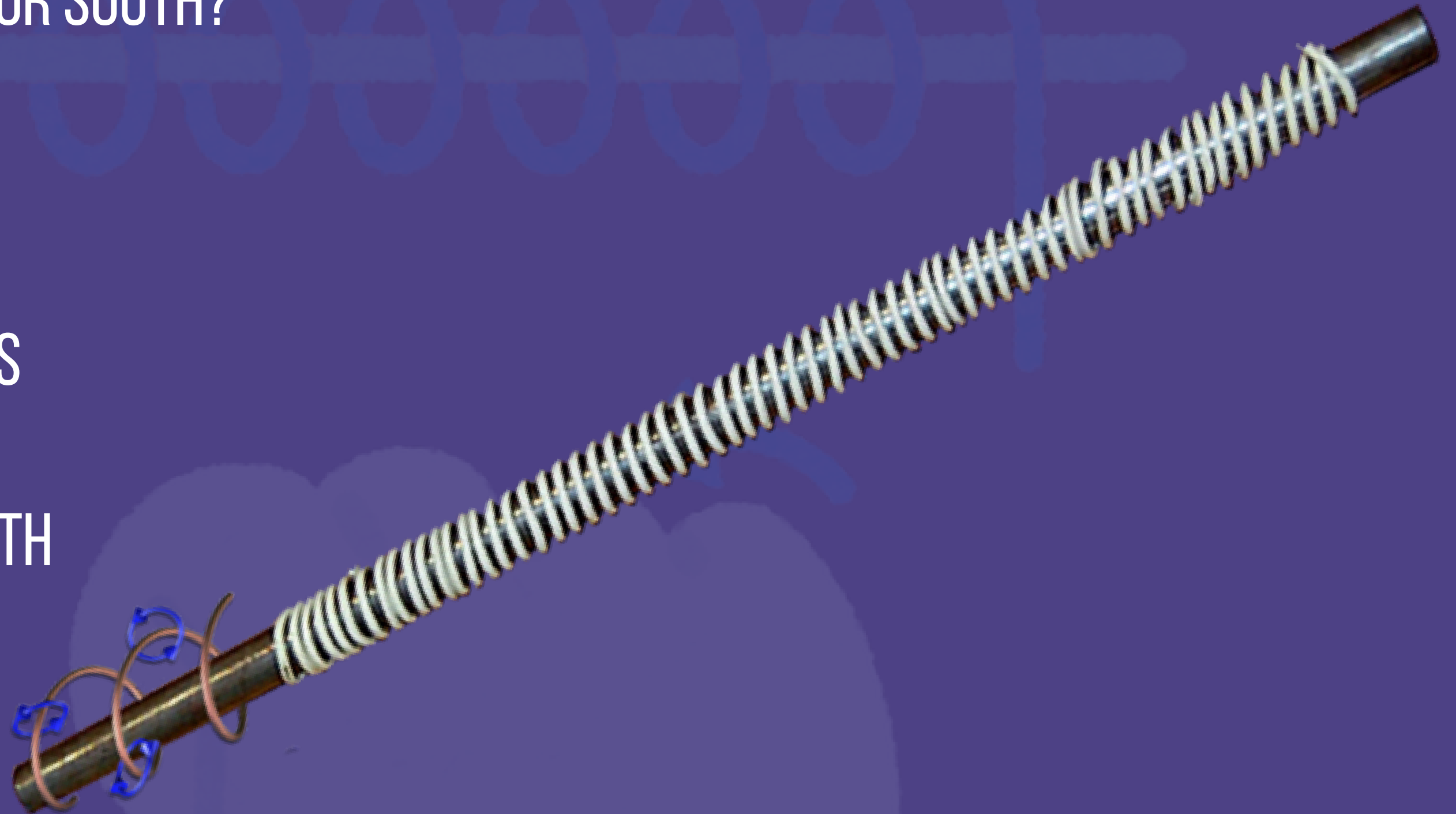
EXTENSIONS:

- 2 BATTERIES
 - IN LINE?
- SMALLER/LARGER IRON CORE
- ALUMINUM OR WOODEN ROD
 - WILL THEY WORK?



ELECTROMAGNETISM

- POLES (WINDING DIRECTION)
 - WHICH IS NORTH OR SOUTH?
 - RIGHT HAND RULE
- VARIABLES:
 - NEATNESS
 - NUMBER OF WINDS
 - WIRE GAUGE
 - BATTERY STRENGTH
 - CORE SIZE
 - TEMPERATURE
 - PRECISION



- Speakers work with a permanent magnet in an electromagnet coil
 - Music sent as electrical current creates flux in the coil, causing the magnet to vibrate
- Vibration creates the sound we hear



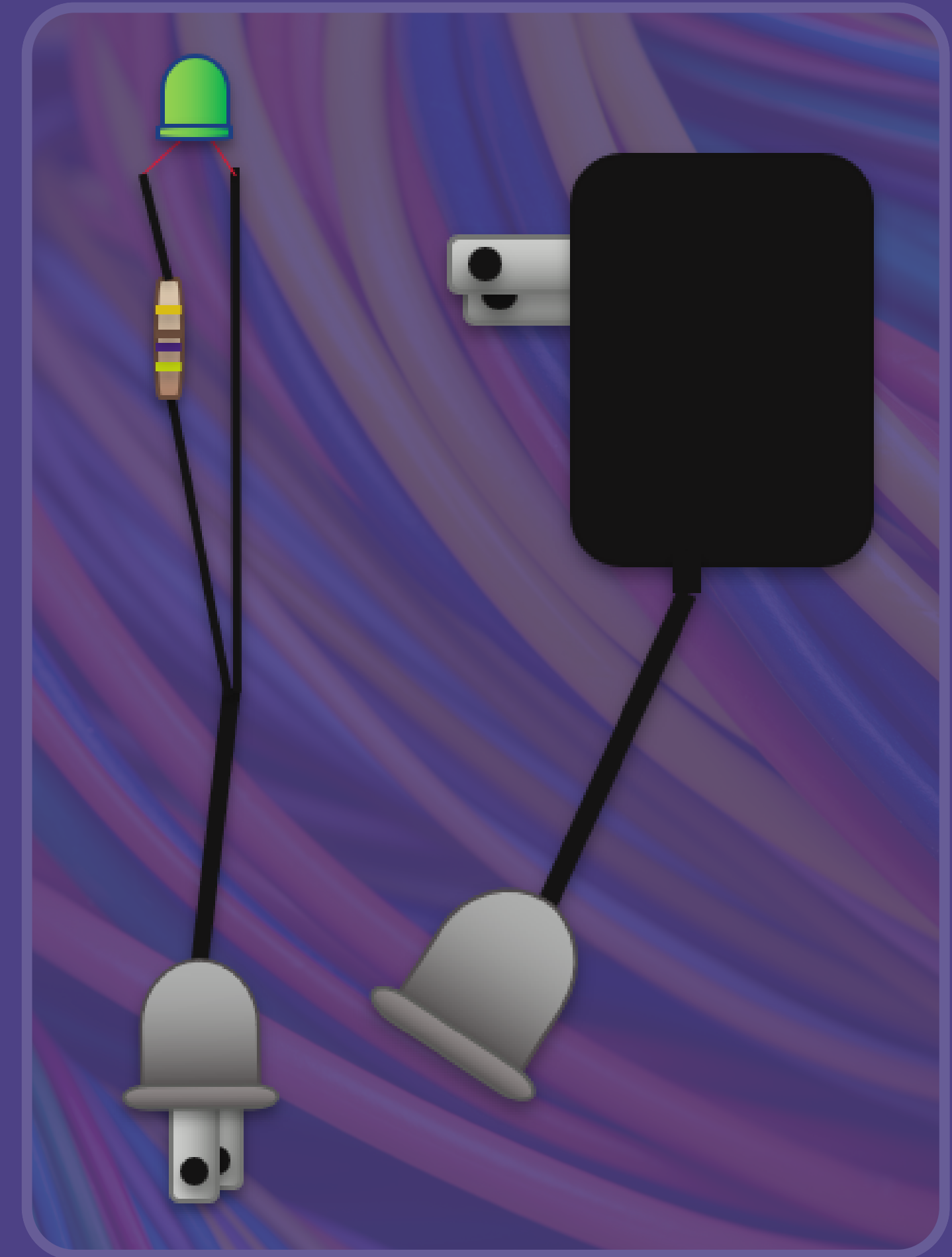
Make a Speaker

AC/DC CURRENT DETECTOR

Device shows AC current

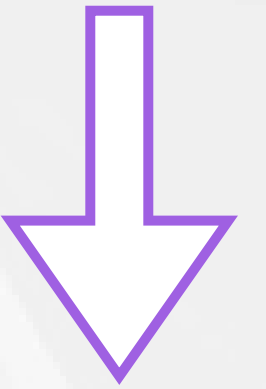
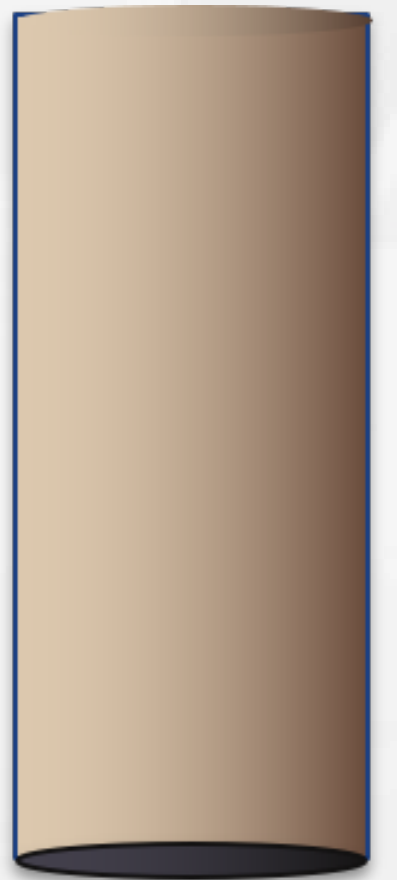
Materials

- Bi-color LED
- ½ Watt, 400–500 Ohm resistor
- Lamp cord
- 2-prong plug
- 2-prong socket
- Electrical tape
- 9-volt AC adaptor/transformer



INDUCTION BY GRAVITY

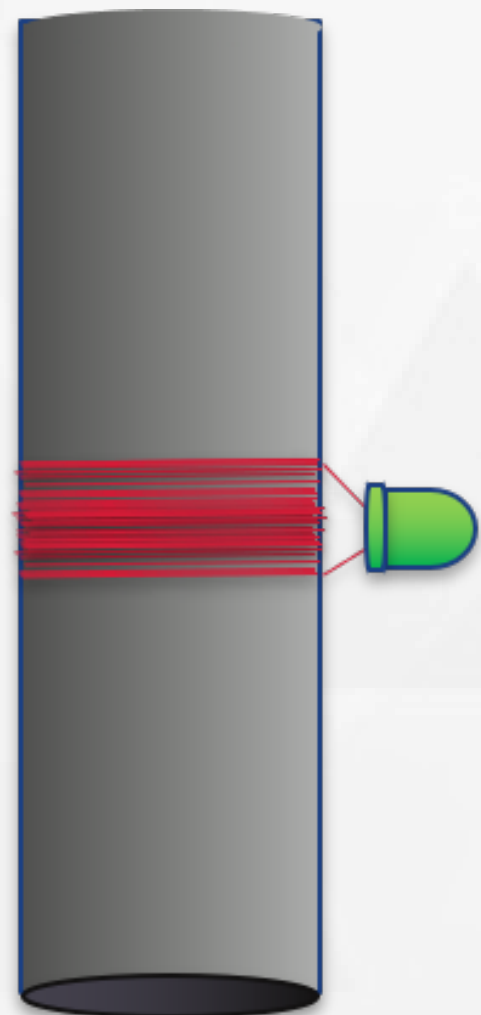
- Movement of magnetic field by a conductor creates motion of electrons
 - Current is induced
 - Basis of electric generators
- Gravity pulls magnet past conducting coil
 - Induced current in copper tube created Eddy currents
 - Currents repel magnet



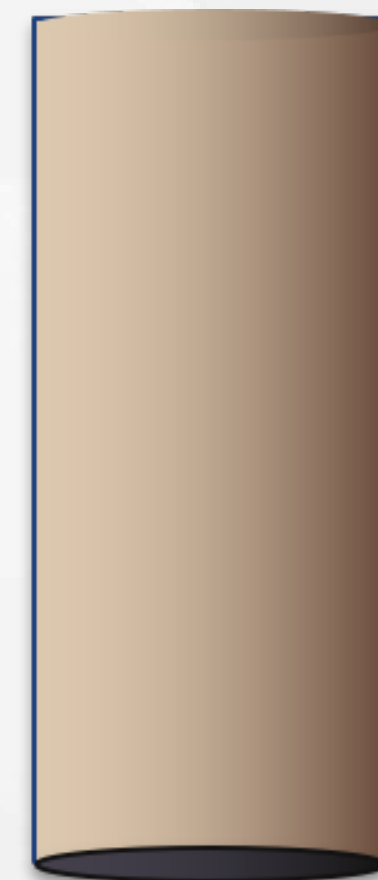
INDUCTION BY GRAVITY



- Movement of magnetic field by a conductor creates motion of electrons
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 - Currents repel magnet



- Movement of magnetic field by a conductor creates motion of electrons
 - Current is induced
 - Basis of electric generators
- Gravity pulls magnet past conducting coil
- Induced current lights LEDs



INDUCTION BY GRAVITY PART II

PLOTTING ELECTRIC FIELD LINES

[MAGLAB HOME](#) [KIDS](#) [TEENS](#) [ADULTS / COLLEGE STUDENTS](#) [TEACHERS](#) or [CUSTOM SEARCH](#)

MAGNET⚡ACADEMY

FROM THE NATIONAL HIGH MAGNETIC FIELD LABORATORY

EXPLORING THE WIDE
WORLD OF ELECTRICITY
AND MAGNETISM

[WATCH & PLAY ▾](#) [LEARN THE BASICS ▾](#) [EXPLORE HISTORY ▾](#) [TRY THIS AT HOME](#) [PLAN A LESSON](#) [FOLLOW THE LINKS](#)

Plotting Electric Field Lines

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Detailed instructions for teachers on conducting a hands-on lesson on plotting electric fields lines.

Concepts covered

- Electric fields
- Forces

Time

This activity requires about 1-1.5 hours to complete.

Background

There are four fundamental interactions that occur in nature; in physics they are referred to as fundamental forces. The four forces are gravitational, electromagnetic, strong nuclear and weak nuclear. For this lesson we will focus on the electromagnetic force, specifically the force produced by an electric field (E).

The concept of the electric field is a bit esoteric compared to, let's say, a gravitational field because we can interact much more easily with a gravitational field than we can with an electric field. If we take a ball (basketball, golf ball, baseball, etc.) and drop it, we see that it falls toward the Earth. This happens because the ball is in a gravitational field and the gravitational field produced by the Earth interacts with the mass of the ball. We assume, for the most part, that the gravitational field experienced by the ball is uniform, therefore, the ball falls straight from your hand to the ground. The force exerted by the field on the ball is $F = mg$ (force = mass of the ball x gravity) **Figure 1.**

Uniform gravitational field, g

What's the MagLab?

Magnet Academy is brought to you by the National High Magnetic Field Laboratory — the largest, most high-powered magnet lab in the world.

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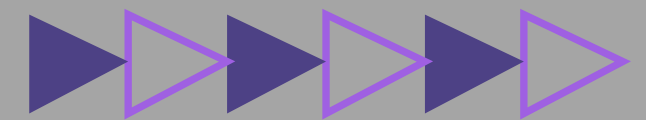
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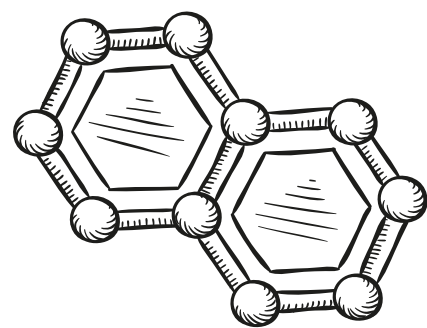
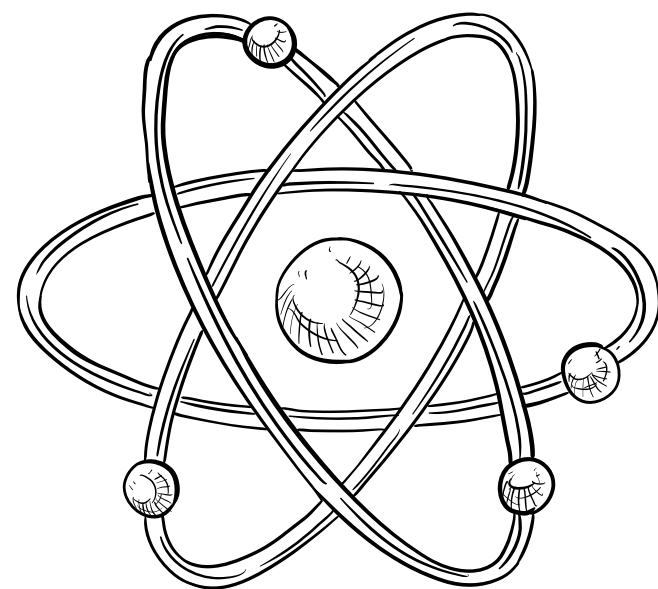
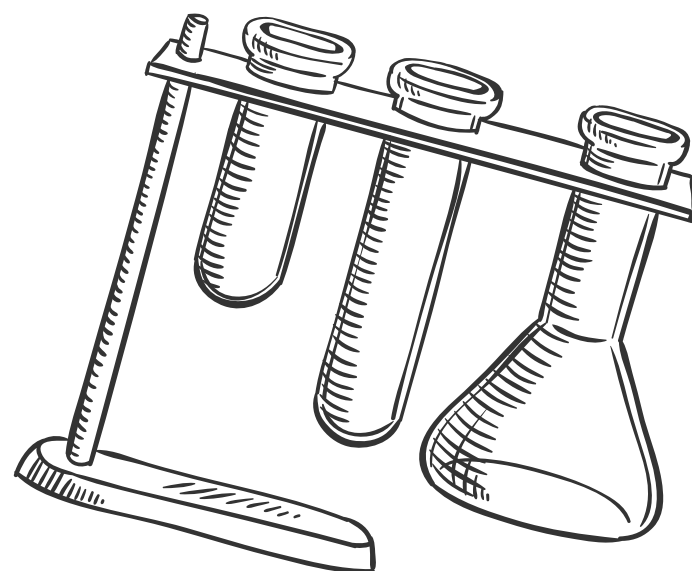
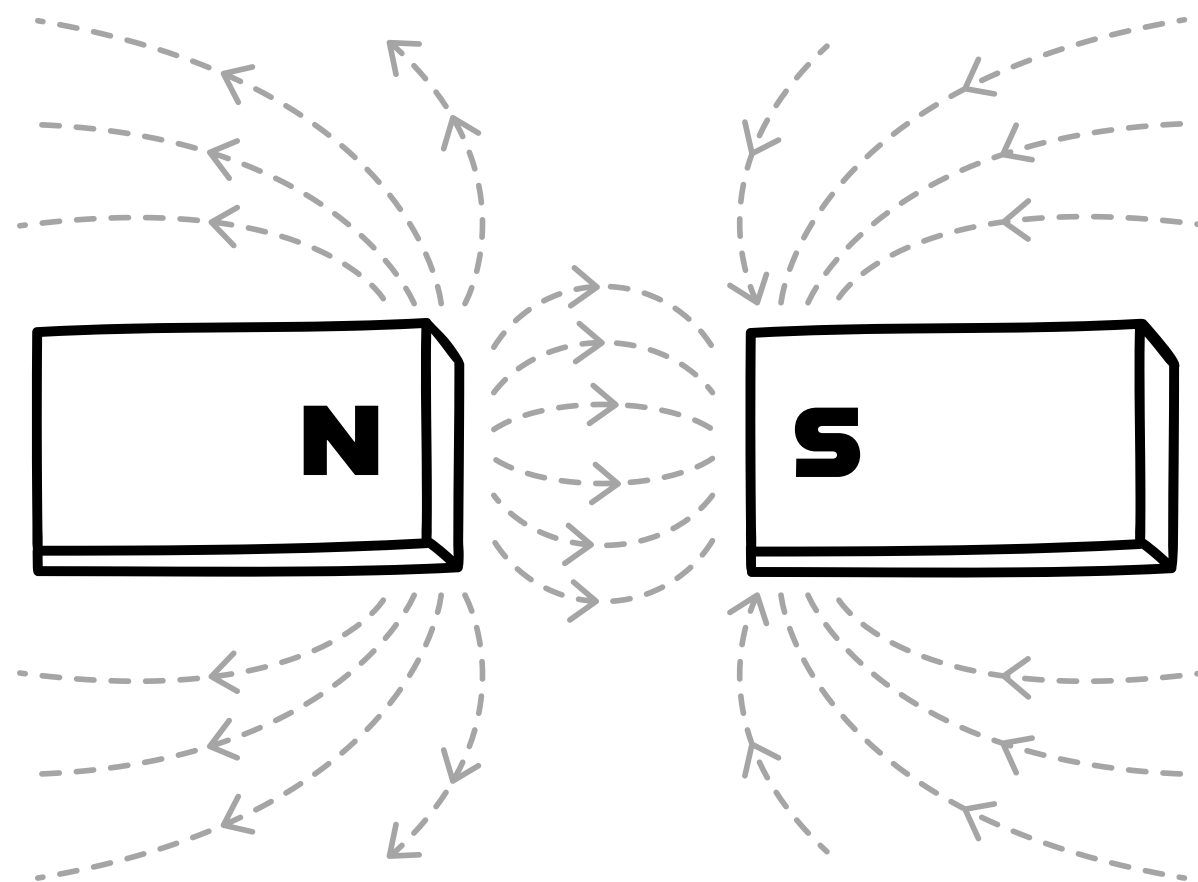
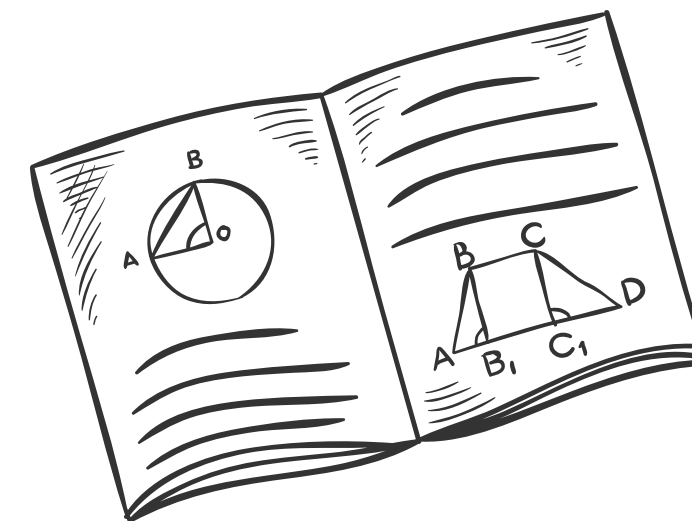
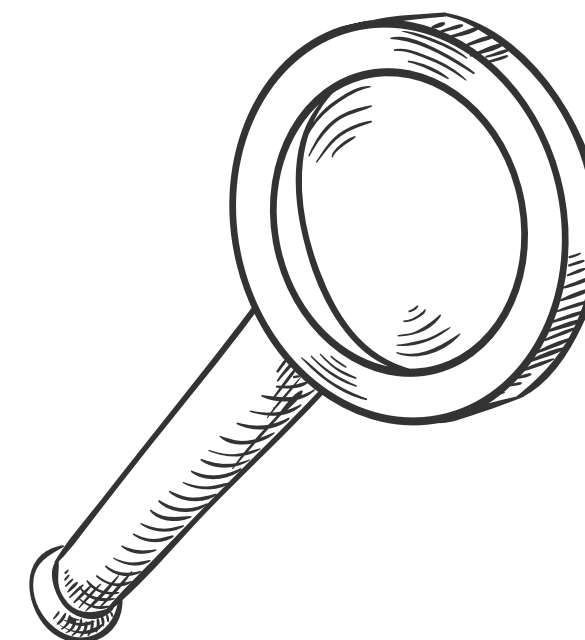
Grade (U.S.)
-- Select Grade (U.S.) -- ▾

[Find My Science!](#) [Reset](#)

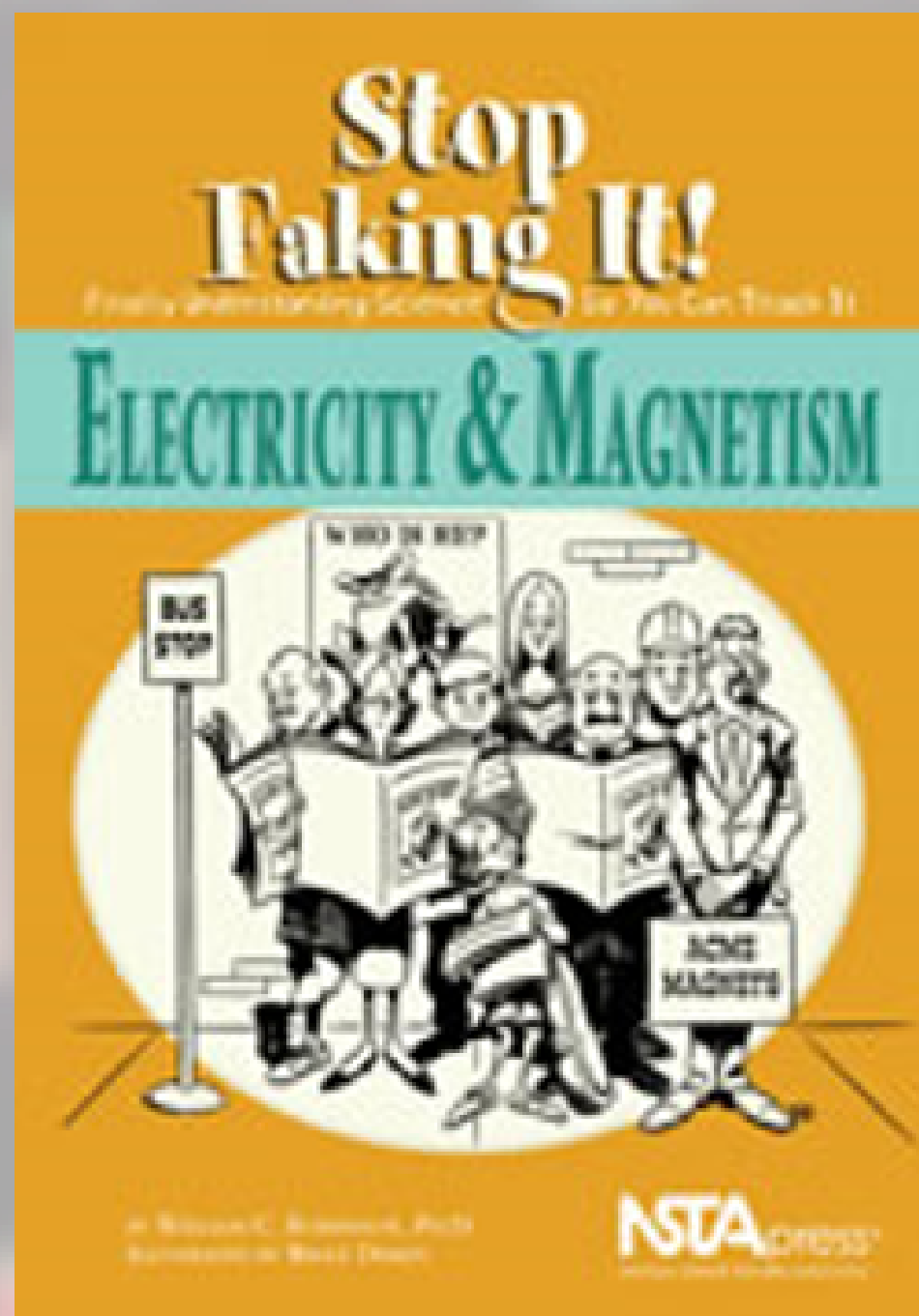
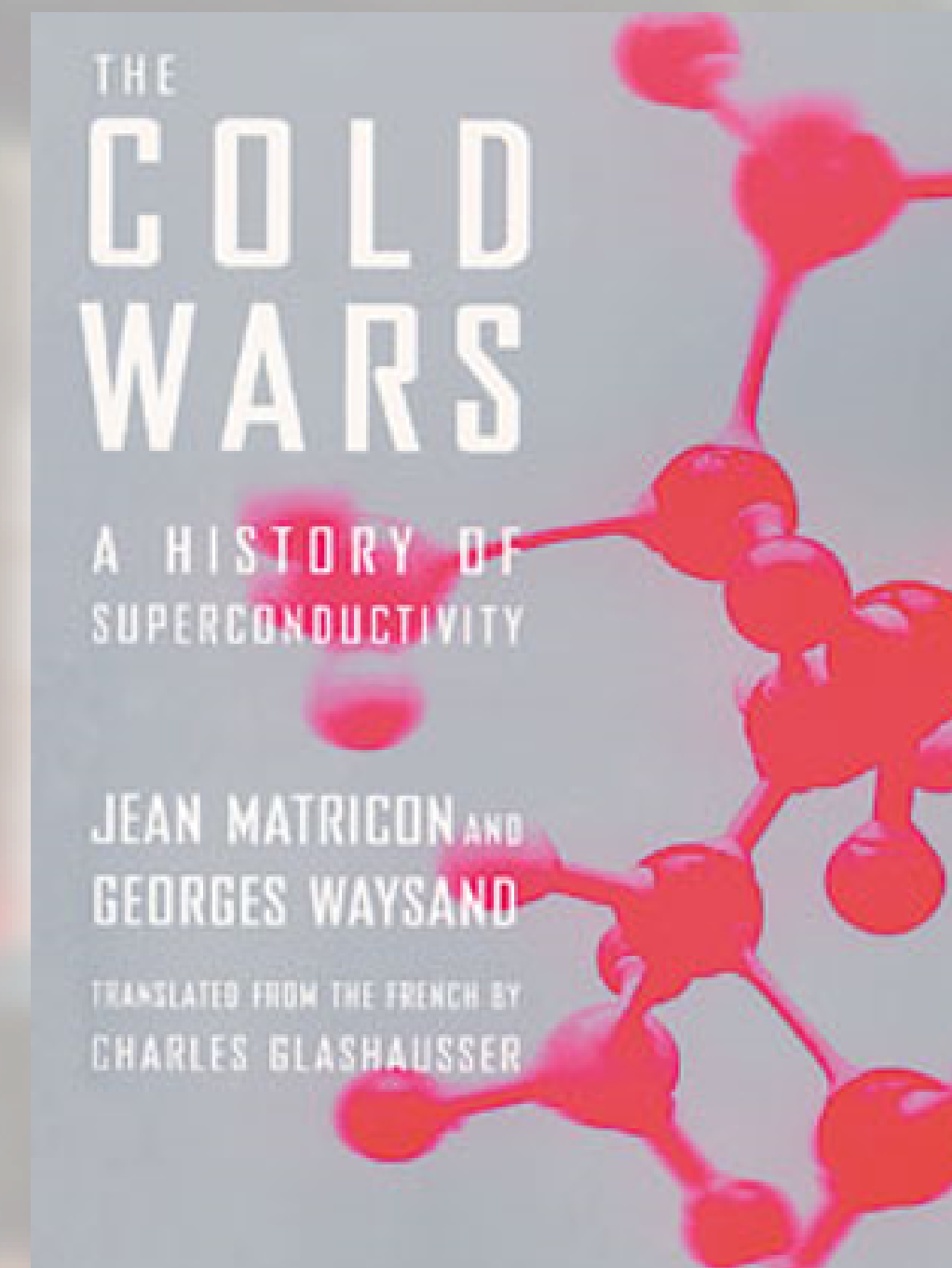
MORE LESSON PLAN IDEAS

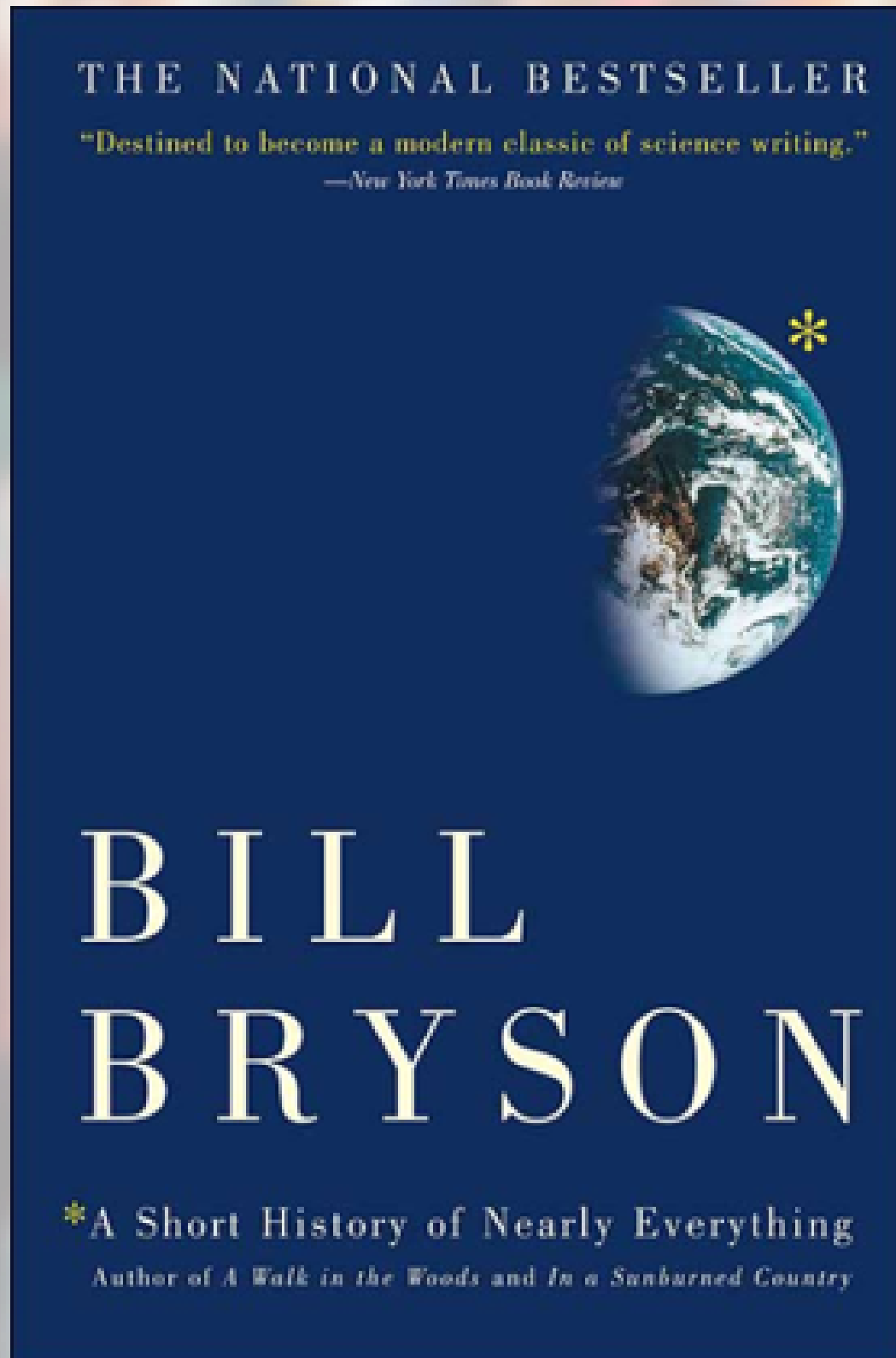
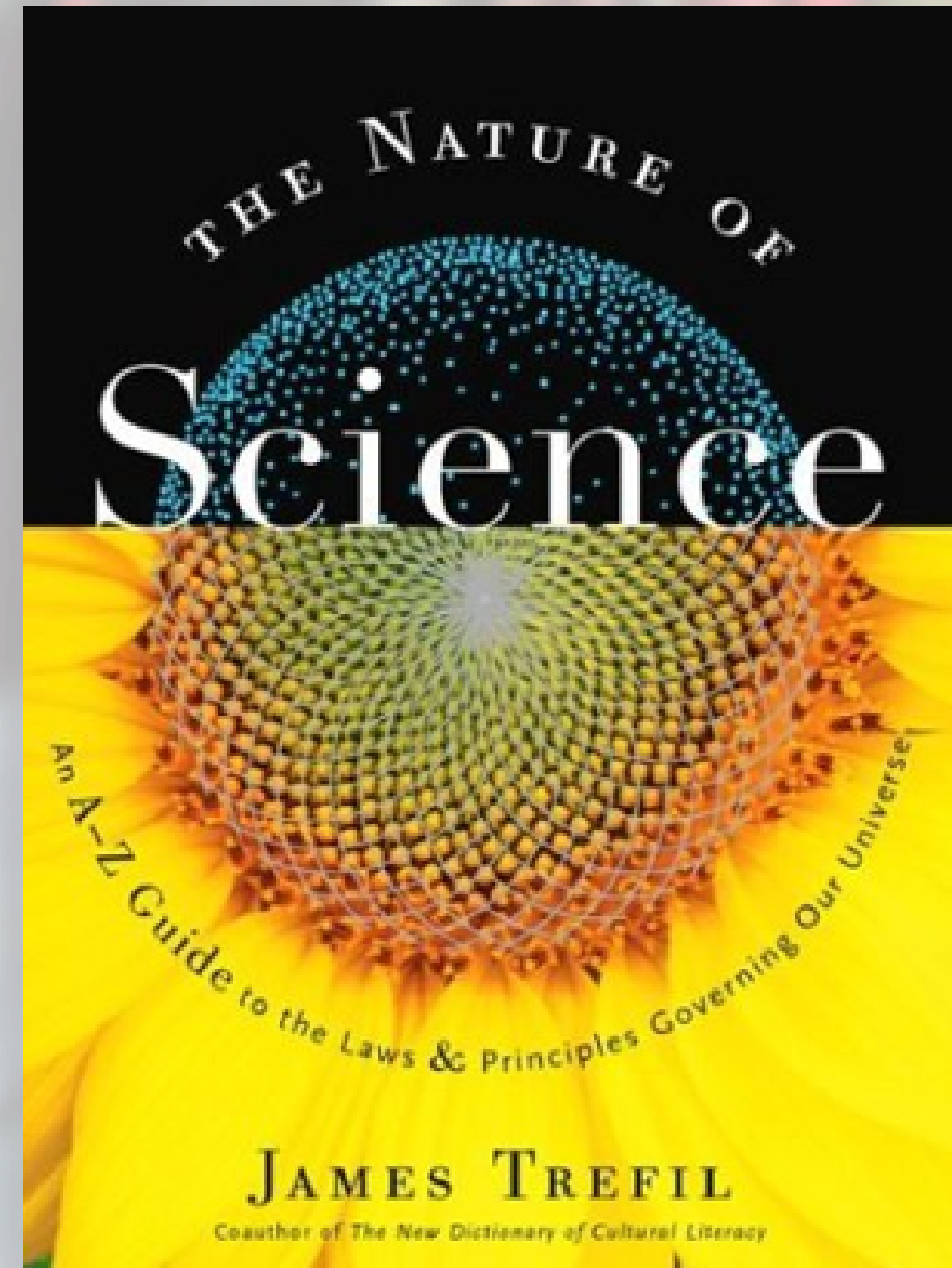
- Electric Motors
- Ion Motors
- Homopolar Motors
- Permanent Magnets
- Making Microphones

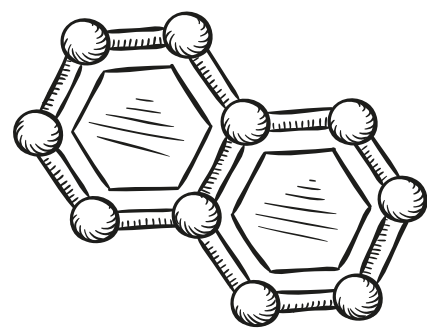
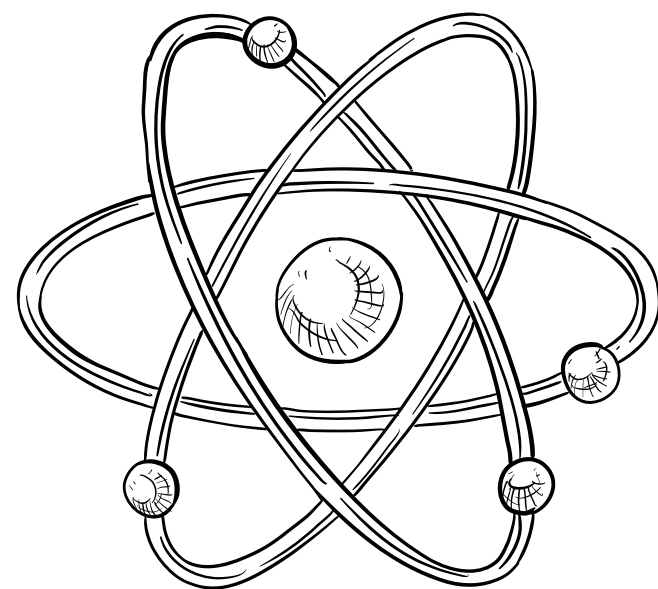
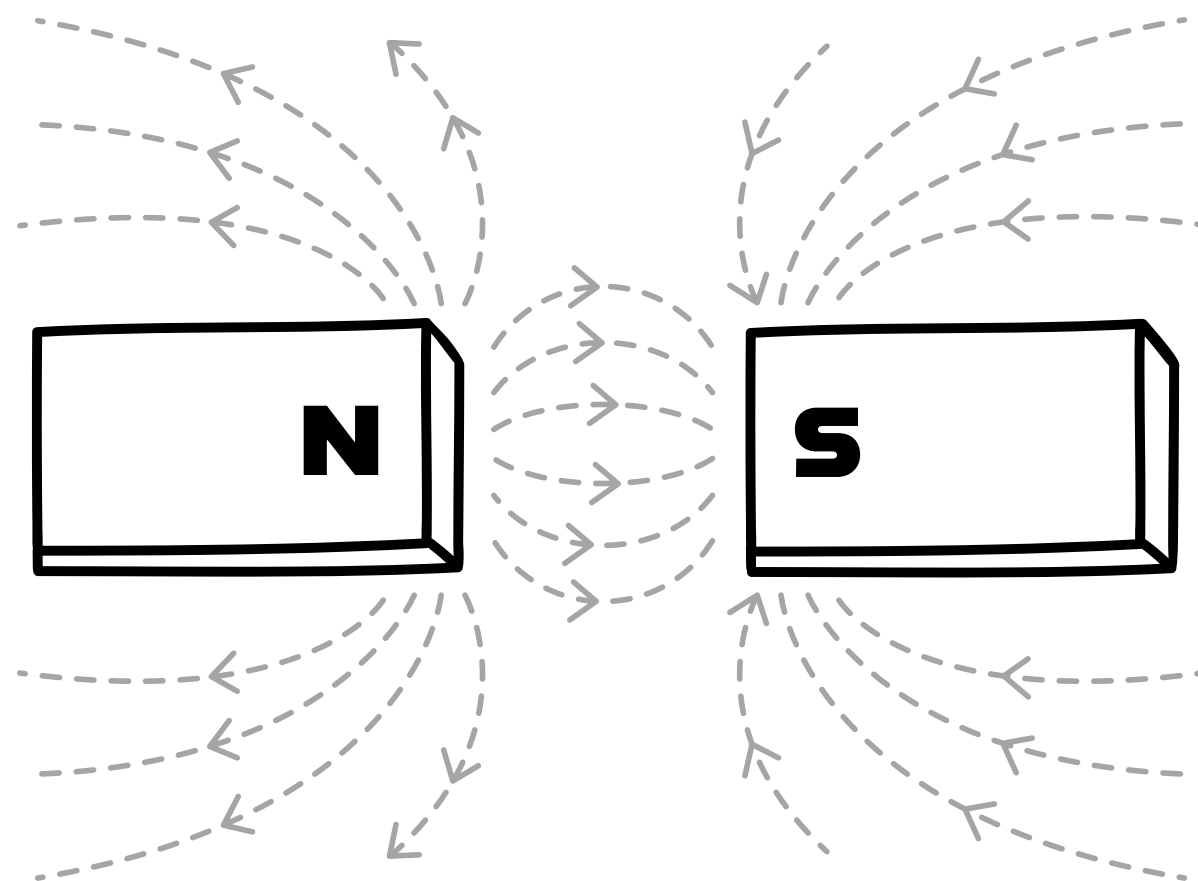
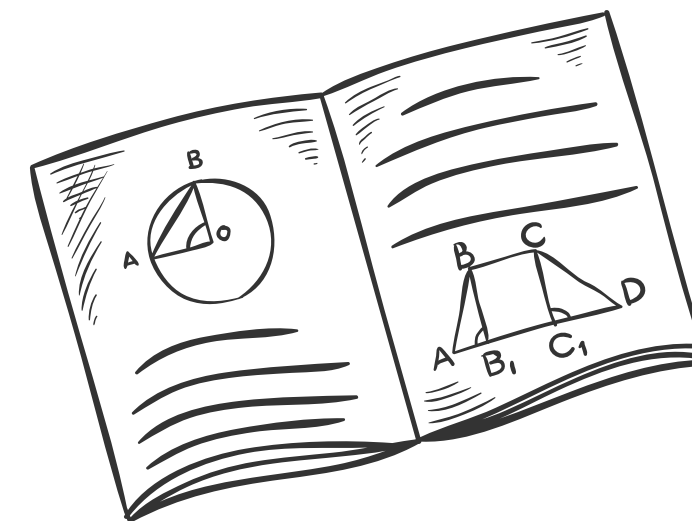
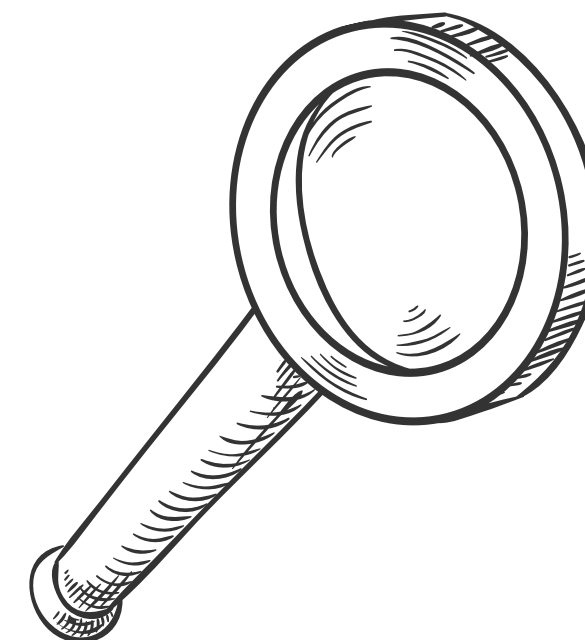
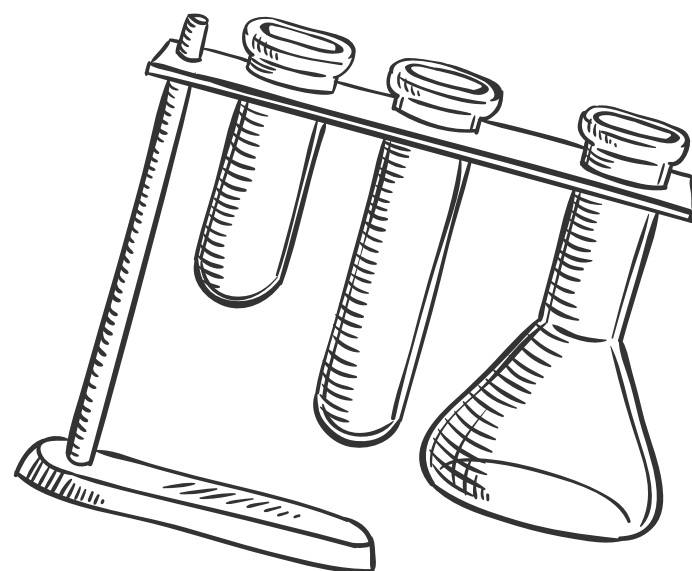




ADDITIONAL ELECTRO- MAGNETISM RESOURCES







MAGLAB RESEARCH EXPERIENCE

OPPORTUNITY: RESEARCH EXPERIENCES FOR TEACHERS (RET)

This exciting summer program gives K-12 and informal STEM educators from across the country the chance to learn how to incorporate MagLab science (materials science, chemistry, and physics) into their STEM lesson plans.

- Summer Program
- 1 Week in Person
 - In the MagLab
- 5 weeks virtual
 - Wherever Home Is
- \$3600 stipend

What do you have to do?

- Complete online application
- Complete & submit lesson plan
- Sell yourself
 - 12 spots, 300+ applications

2026 MAGLAB RET

- Week in Tallahassee we supply
 - Housing
 - Travel stipend
- Program is open to Elementary, Middle, and High School teachers



PROGRAM OVERVIEW



Focus of the program

- Nature of Science
- Argument Driven Inquiry
- Communicating in science
- Experimental Design
- Culturally Responsive Pedagogy



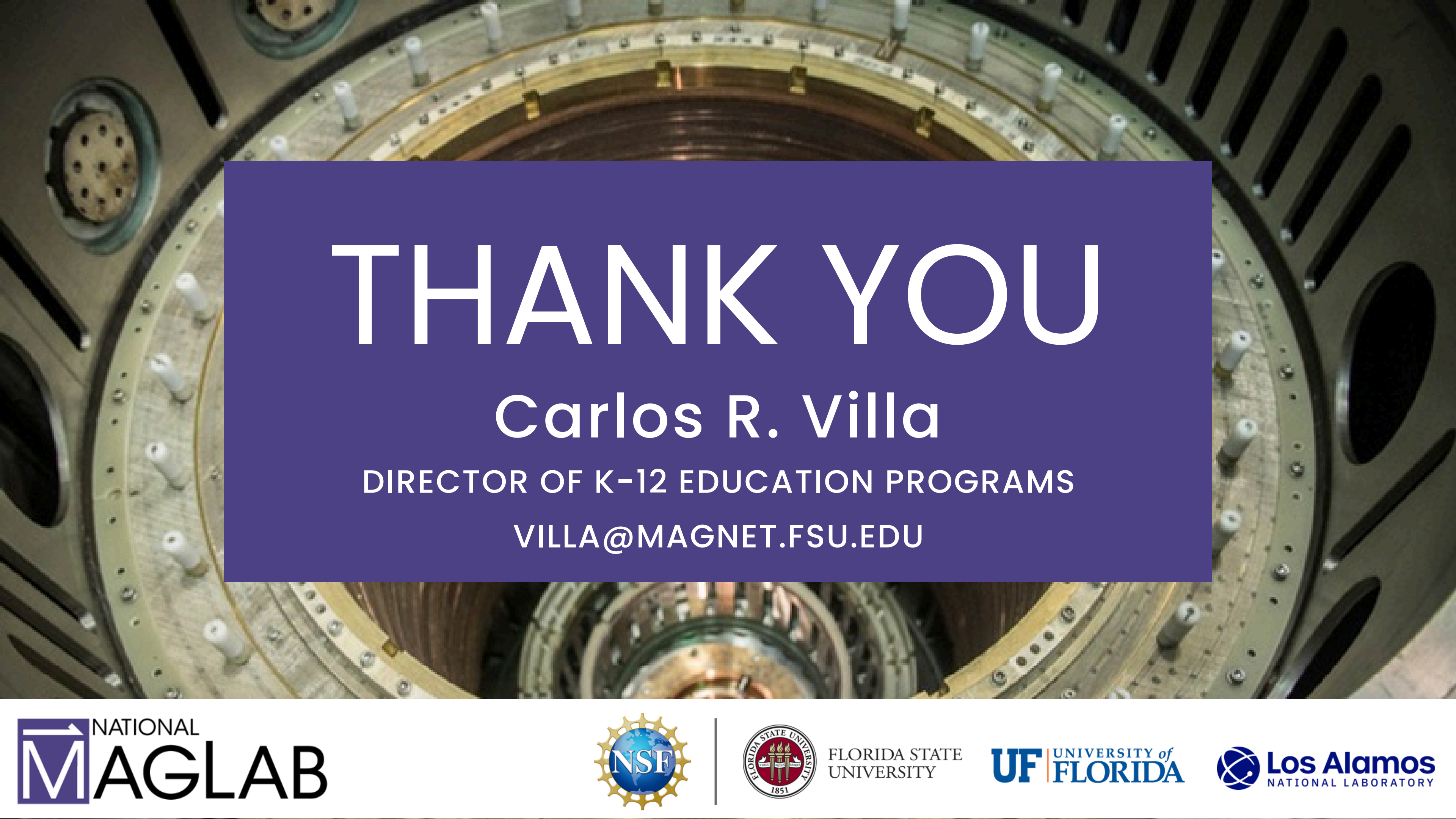
Scientist Advisor

- Work with a scientist
- Build a unique lesson plan



Topics for Lesson Plan Research

- Materials Engineering
- Superconductivity
- Electron Scanning Microscopy
- Condensed Matter



THANK YOU

Carlos R. Villa

DIRECTOR OF K-12 EDUCATION PROGRAMS

VILLA@MAGNET.FSU.EDU