Lectures: Physics 3306

Provides an introduction to a wide variety of topics in classical (pre-quantum) physics as a bridge to prepare students for subsequent upper-level courses in physics. The topics covered include thermodynamics, fluid mechanics, mechanical waves, optics, radiation, electromagnetic phenomena, atoms, and laboratory techniques. Prerequisites: C- or better in PHYS 1106; and in PHYS 1304 or PHYS 1308.

Saptaparna Bhattacharya

April 17th, 2026

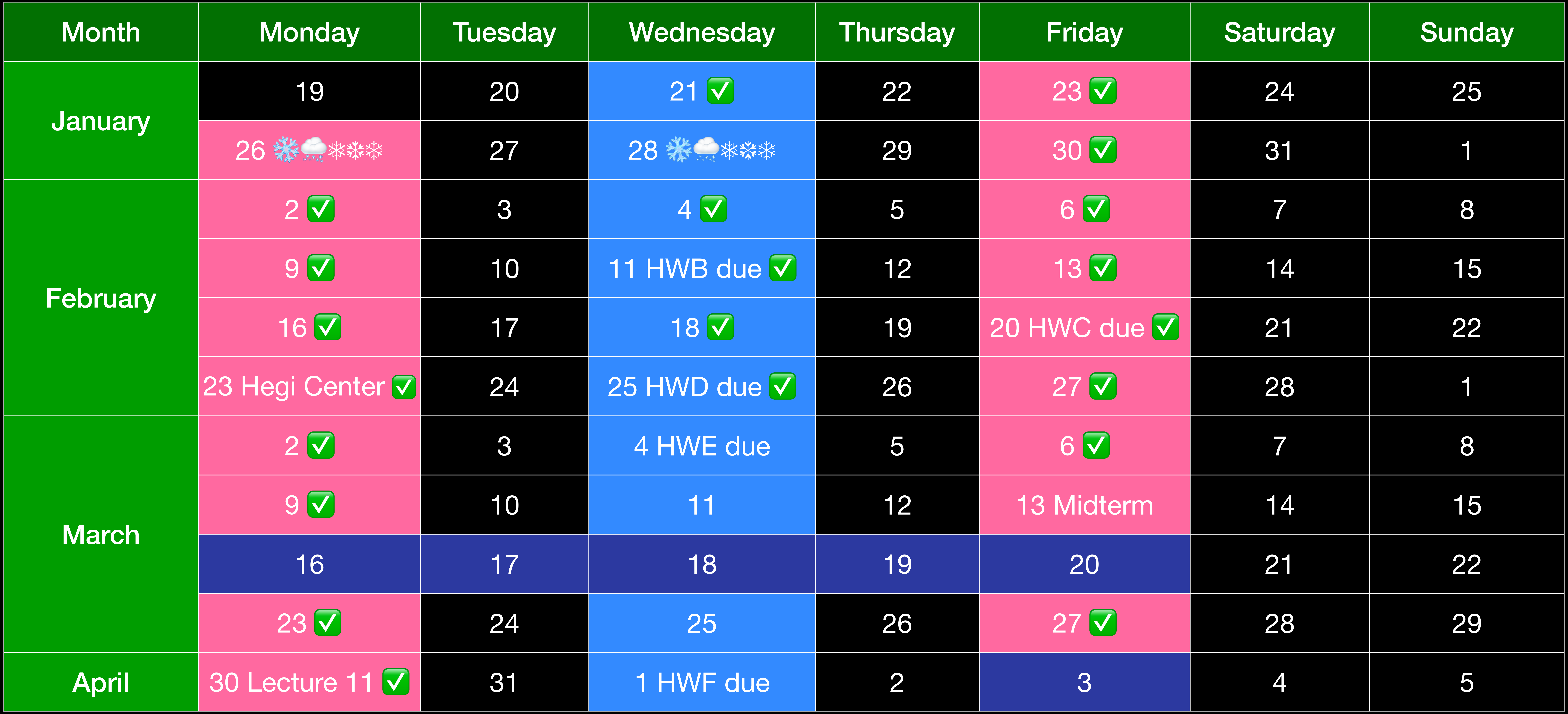
Based on Simon Dalley's lectures taught in Spring 2025

Labs

Lectures

Schedule

No class



Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
January	19	20	21 ✅	22	23 ✅	24	25
	26 ❄️🌨️❈❆❄	27	28 ❄️🌨️❈❆❄	29	30 ✅	31	1
February	2 ✅	3	4 ✅	5	6 ✅	7	8
	9 ✅	10	11 HWB due ✅	12	13 ✅	14	15
	16 ✅	17	18 ✅	19	20 HWC due ✅	21	22
	23 Hegi Center ✅	24	25 HWD due ✅	26	27 ✅	28	1
March	2 ✅	3	4 HWE due	5	6 ✅	7	8
	9 ✅	10	11	12	13 Midterm	14	15
	16	17	18	19	20	21	22
	23 ✅	24	25	26	27 ✅	28	29
April	30 Lecture 11 ✅	31	1 HWF due	2	3	4	5

Labs

Lectures

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Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
April	6 Midterm 2 ✅	7	8 HWG due	9	10 Lecture 15 ✅	11	12
	13 Lecture 16 ✅	14	15 HWH due	16	17 Lecture 17 ✅	18	19
	20 Lecture 18	21	22 HWI due	23	24 Lecture 19	25	26
May	27 Lecture 20	28	29 HWJ due	30	1 Lecture 21	2	3
	4 Lecture 22	5 Lecture 23	6	7	8	9	10

Halliday: 26.2 - 26.4

Group task

- Cruise: Magnetic dipole group ✅
- Avi: Gauss' law ✅
- Charli+Cecilia: Semiconductors
- Marissa: Faraday's law ✅
- John Ridge: Ampere's law
- Ruzbeh: Capacitors
- John Calmette: Coulomb's law

Key concepts: Current density

- Study flow of charge through a cross section of a conductor at a particular point
  - Use the concept of current density, $\vec{J}$,
  - $i = \int \vec{J} \cdot d\vec{A}$
  - If the current is uniform across the surface and parallel to $d\vec{A}$, then,
  - $i = \int J\, dA = J \int dA = JA$
- Drift speed:
  - When a conductor does not have a current through it, its conduction electrons move randomly, with no net motion in any direction
  - When the conductor does have a current through it, these electrons actually still move randomly, but now they tend to *drift* with a drift speed (v_d) *in the direction opposite to that of the applied electric field that causes the current*

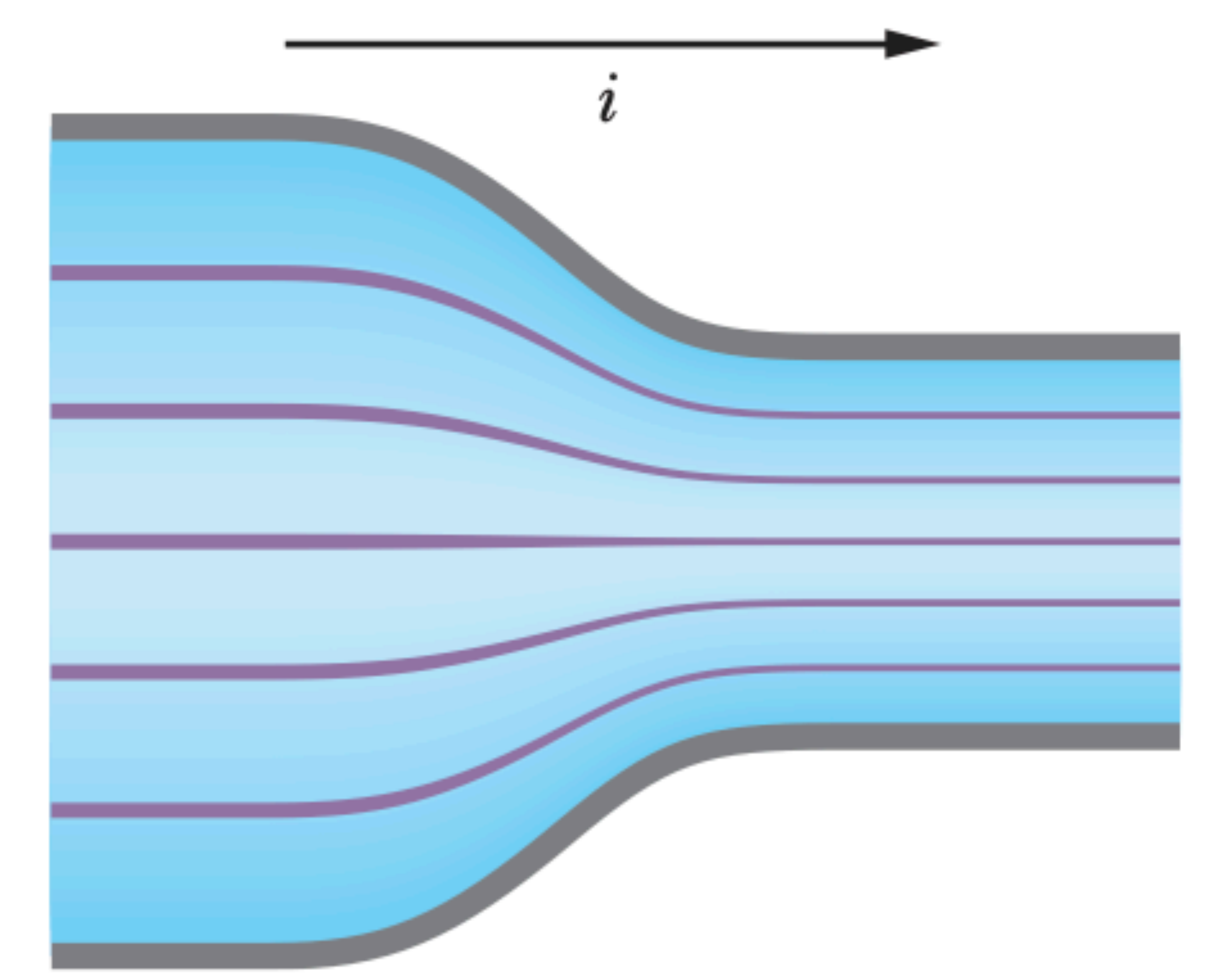

Figure 26-4 Streamlines representing current density in the flow of charge through a constricted conductor.

Key concepts: Current density

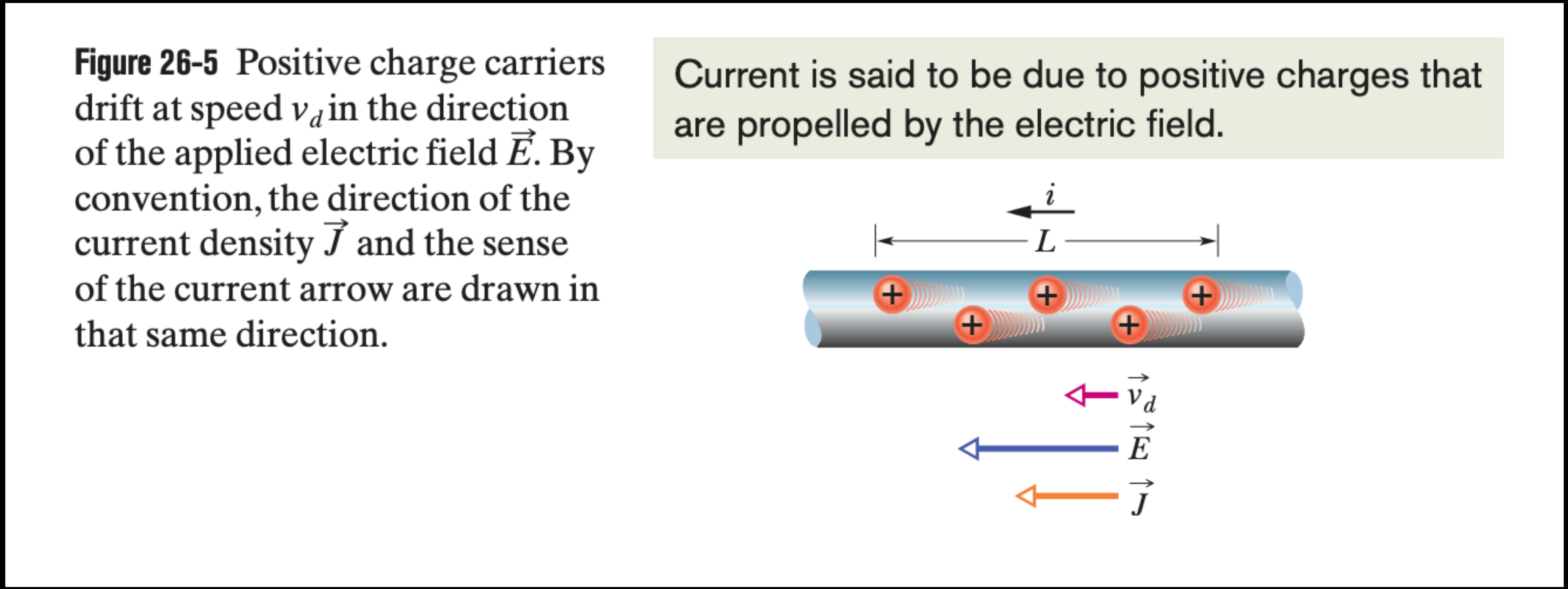

Figure 26-5 Positive charge carriers drift at speed v_d in the direction of the applied electric field $\vec{E}$. By convention, the direction of the current density $\vec{J}$ and the sense of the current arrow are drawn in that same direction.

Current is said to be due to positive charges that are propelled by the electric field.

- Number of large carriers in a length L of the wire is nAL
- Charge of each carrier (e), total charge: $q = (nAL)e$
- Time interval: $t = \dfrac{L}{v_d}$
- $i = \dfrac{q}{t} = \dfrac{nALe}{L/v_d} = nAev_d$
- $v_d = \dfrac{i}{nAe} = \dfrac{J}{ne}$
- $\overrightarrow{J} = (ne)\overrightarrow{v_d}$

Conduction electrons are moving leftward in a wire. Are the following leftward or rightward?

a) The current

b) The current density

c) The electric field

Conduction electrons are moving leftward in a wire. Are the following leftward or rightward?

a) The current R

b) The current density R

c) The electric field R

Since conduction electrons (which carry a negative charge) are moving **leftward**, we can determine the direction of the other quantities based on standard conventions in electromagnetism:

a) The current: Rightward By convention, electric current is defined as the direction of *positive* charge flow. Therefore, the direction of conventional current is always opposite to the direction of the flow of negative electrons.

b) The current density: Rightward Current density (J) is a vector quantity that points in the exact same direction as the conventional current.

c) The electric field: Rightward The electric field (E) within a conductor drives the current and points in the same direction as the conventional current and current density. Alternatively, because electrons are negatively charged, they experience a force (and thus drift) in the direction opposite to the applied electric field (F=qE). For electrons to drift leftward, the electric field must point rightward.

Key concepts: Ohm's law

- If we apply the same potential difference between the ends of geometrically similar rods of copper and of glass, very different currents result.
- The characteristic of the conductor that enters here is its electrical **resistance.**
- We determine the resistance between any two points of a conductor by applying a potential difference V between those points and measuring the current i that results
- The resistance R is then: $R = \dfrac{V}{i}$
- **Ohm's law** is an assertion that the current through a device is *always* directly proportional to the potential difference applied to the device.

The following table gives voltage (in volts) and current (in milli amperes) for two devices.

Which devices do or do not obey Ohm’s law?

	Device 1	**Device 2**
V	i	i
2.00	4.50	1.50
3.00	6.75	2.20
4.00	9.00	2.80

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Ohm's law states that the current (i) through a conductor is directly proportional to the voltage (V) applied across it, provided temperature and other physical conditions remain constant.

Mathematically, this relationship is expressed as $V=iR$, where R is the resistance. For a device to obey Ohm's Law (an “ohmic” device), the ratio of voltage to current (V/i) must remain **constant** for all data points.

Let's calculate the resistance ($R=V/i$) for each device to see if the ratio holds steady. *(Note: Since voltage is in Volts and current is in milliamperes, V/i will give resistance in kilo-ohms, kΩ)*.

Device 1:

- 2.00 V/4.50 mA=0.444 kΩ
- 3.00 V/6.75 mA=0.444 kΩ
- 4.00 V/9.00 mA=0.444 kΩ

Because the resistance is perfectly constant (0.444 kΩ, or 444 Ω), **Device 1 obeys Ohm's Law.**

Device 2:

- 2.00 V/1.50 mA≈1.333 kΩ
- 3.00 V/2.20 mA≈1.364 kΩ
- 4.00 V/2.80 mA≈1.429 kΩ

Because the calculated resistance changes as the voltage increases, the relationship is not directly proportional. Therefore, **Device 2 does not obey Ohm's Law.**

Key concepts: Conductivity and resistivity

- Define resistivity ρ as:
  - $\rho = \frac{E}{J}$ (scalar form), $\overrightarrow{E}$: electric field, $\overrightarrow{J}$: current density
  - $\overrightarrow{E} = \rho \overrightarrow{J}$
- Conductivity:
  - $\sigma = \frac{1}{\rho}$
  - $\overrightarrow{J} = \sigma \overrightarrow{E}$
- Resistance is a property of an object. Resistivity is a property of a material.

Key concepts: Microscopic view of Ohm’s law

- Consider a conductor, copper, with free electrons moving around
- Electron of mass m is placed in an electric field of magnitude E, Newton’s second law:
  - $a = \dfrac{F}{m} = \dfrac{eE}{m}$
- Time between collisions τ: $v_d = a\tau$
- $v_d = a\tau = \dfrac{eE\tau}{m}$
  - $v_d = \dfrac{J}{ne} = \dfrac{eE\tau}{m}$
- $E = \left(\dfrac{m}{e^2 n\tau}\right) J$
  - $\rho = \dfrac{m}{e^2 n\tau}$

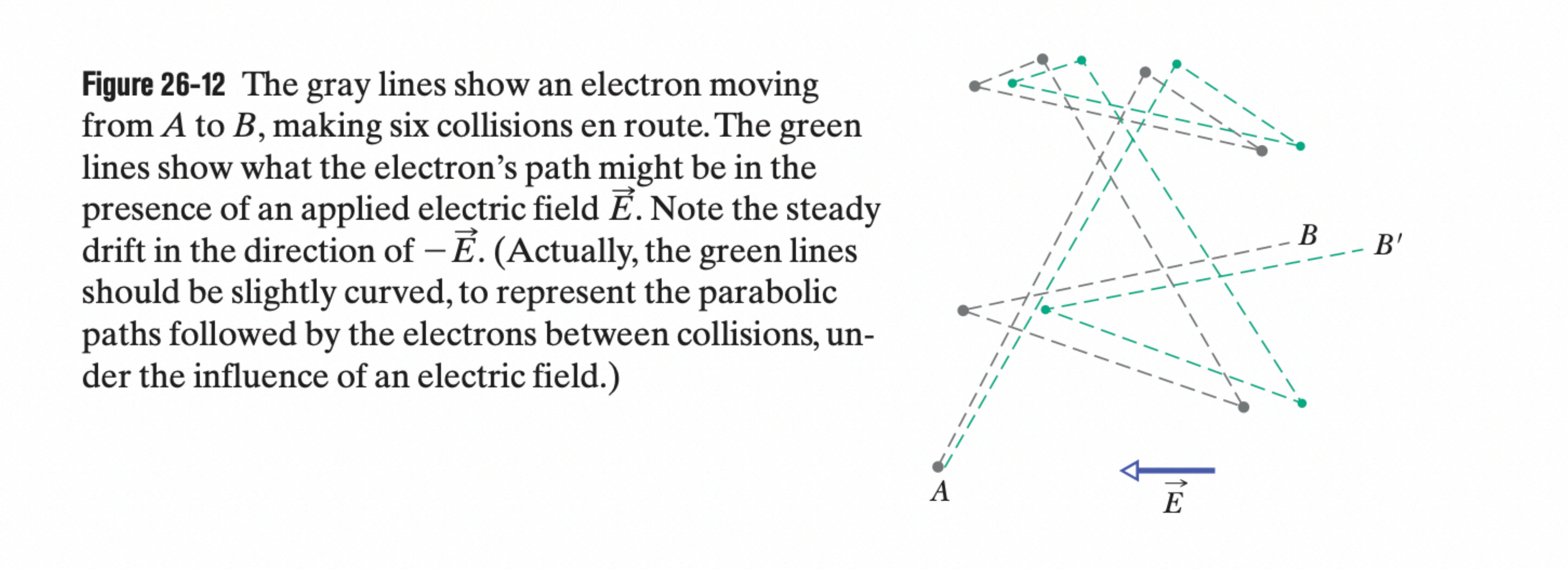

Figure 26-12 The gray lines show an electron moving from A to B, making six collisions en route. The green lines show what the electron’s path might be in the presence of an applied electric field $\vec{E}$. Note the steady drift in the direction of $-\vec{E}$. (Actually, the green lines should be slightly curved, to represent the parabolic paths followed by the electrons between collisions, under the influence of an electric field.)

The conductivity σ of a metal is a function of temperature because

(a)the electron density varies with the temperature

(b) the ion density varies with the temperature

(c) the electric charge varies with temperature

(d) collision time of electrons varies with temperature

(e) all of the above

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What is the magnetic susceptibility χ of a superconductor below its critical temperature?

(Magnetic field $\underline{\mathbf{B}} = \mu_0\ (1+\chi)\ \underline{\mathbf{M}}$, where $\underline{\mathbf{M}}$ is magnetization.)

a) 0

b) 1

c) -1

d) ∞

Key concepts: Conductors

- *Semiconductors:* are materials that have few conduction electrons but can become conductors when they are *doped* with other atoms that contribute charge carriers
- *Superconductors:* are materials that lose all electrical resistance at low temperatures. Some materials are superconducting at surprisingly high temperatures

What is the magnetic susceptibility χ of a superconductor below its critical temperature?

(Magnetic field $\underline{\mathbf{B}} = \mu_0 (1+\chi) \underline{\mathbf{M}}$, where $\underline{\mathbf{M}}$ is magnetization.)

a) 0

b) 1

c) -1

d) ∞

Which of the following is (are) true of a type I superconductor?

a) Infinite conductivity at all temperatures

b) Zero conductivity below a critical temperature

c) Susceptibility -1 at all temperatures

d) Susceptibility -1 below a critical temperature

Which of the following are true of a type I superconductor?

a) Infinite conductivity at all temperatures

b) Zero conductivity below a critical temperature

c) Susceptibility -1 at all temperatures

d) Susceptibility -1 below a critical temperature

Which of the following is (are) true in the mixed state of a type II superconductor?

a) Infinite conductivity

b) Zero magnetic field

c) Both of the above

d) Neither of a) or b)

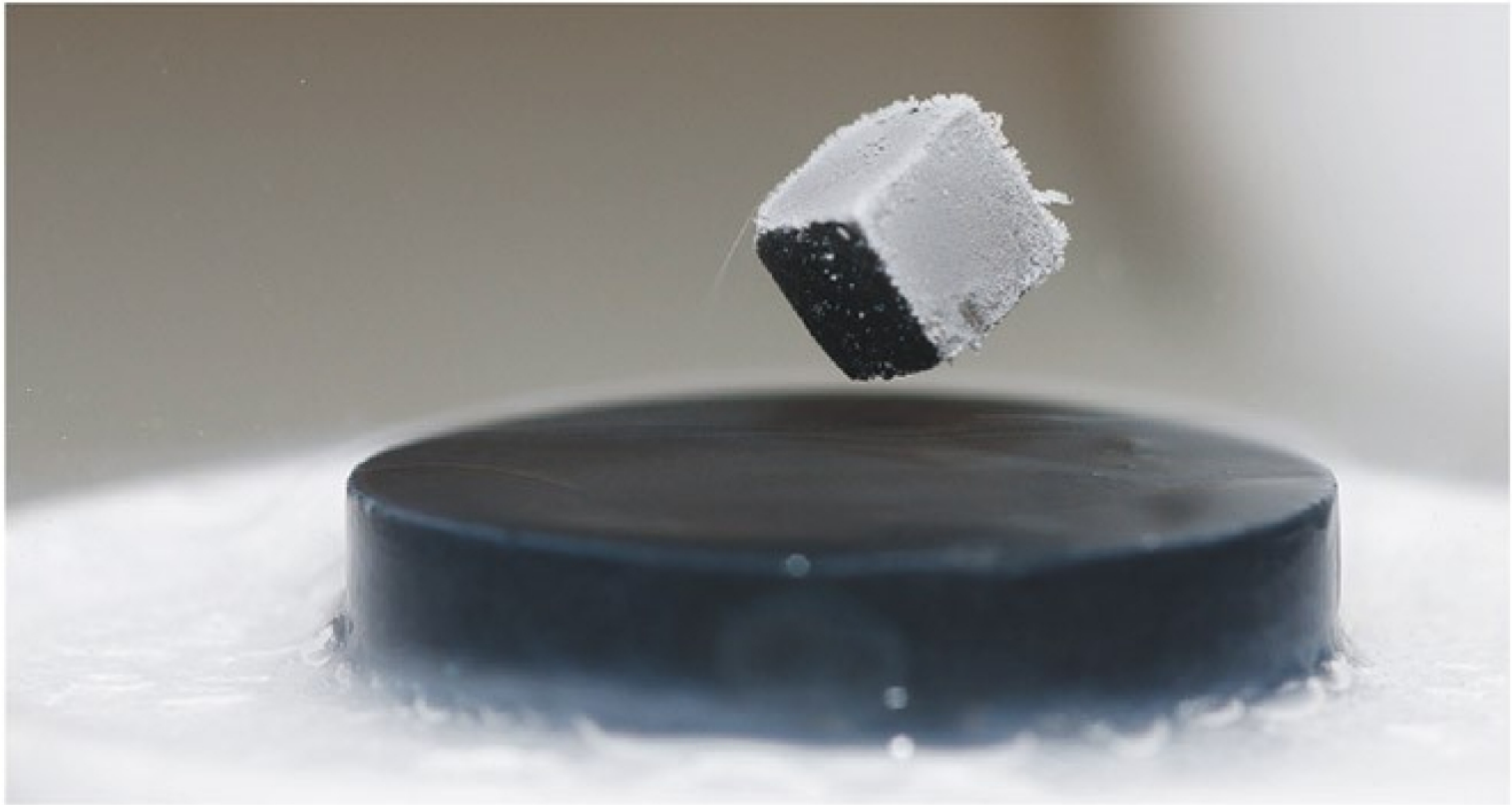
Which of the following is (are) true of the mixed state of a type II superconductor?

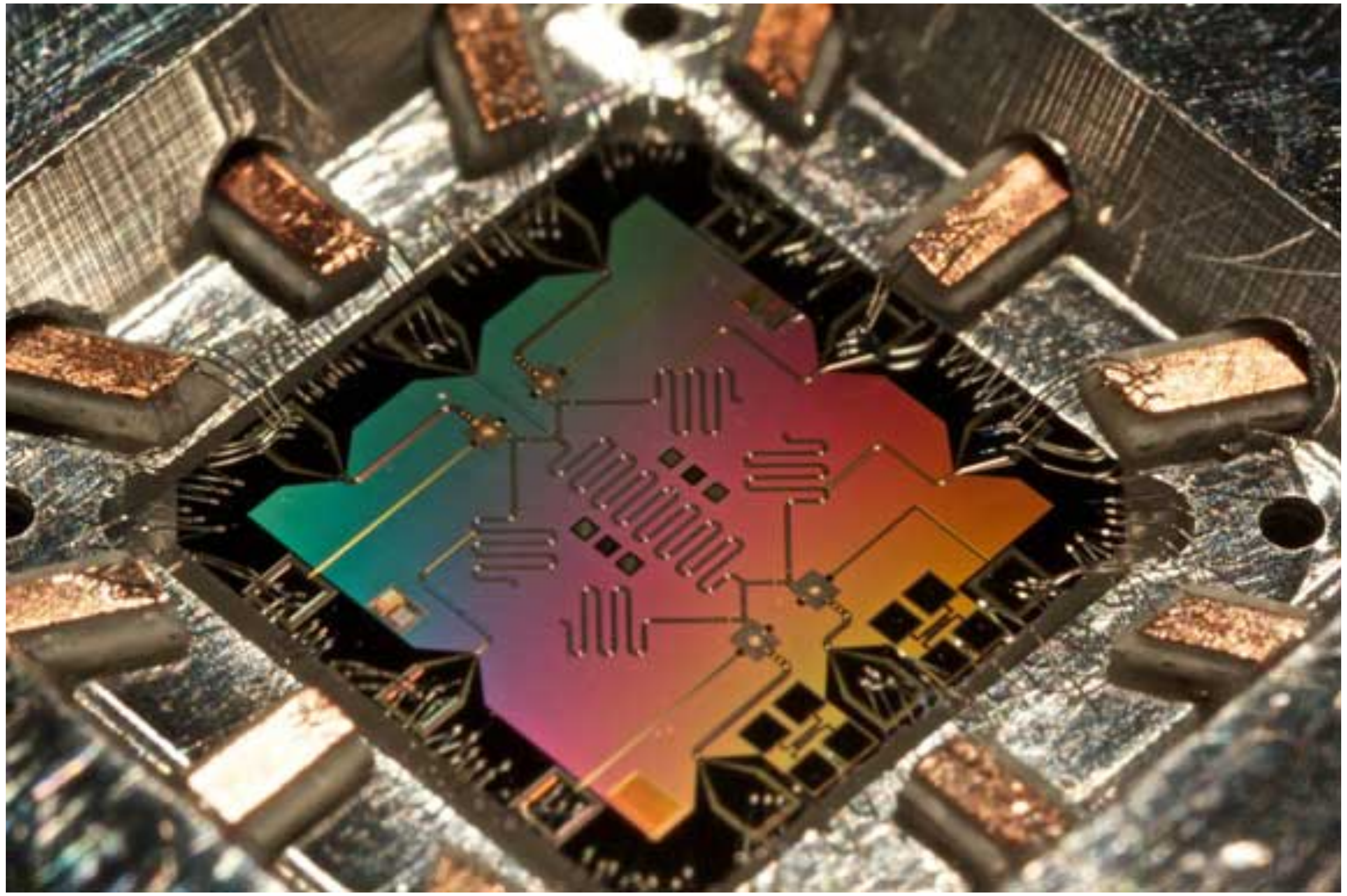
a) Infinite conductivity

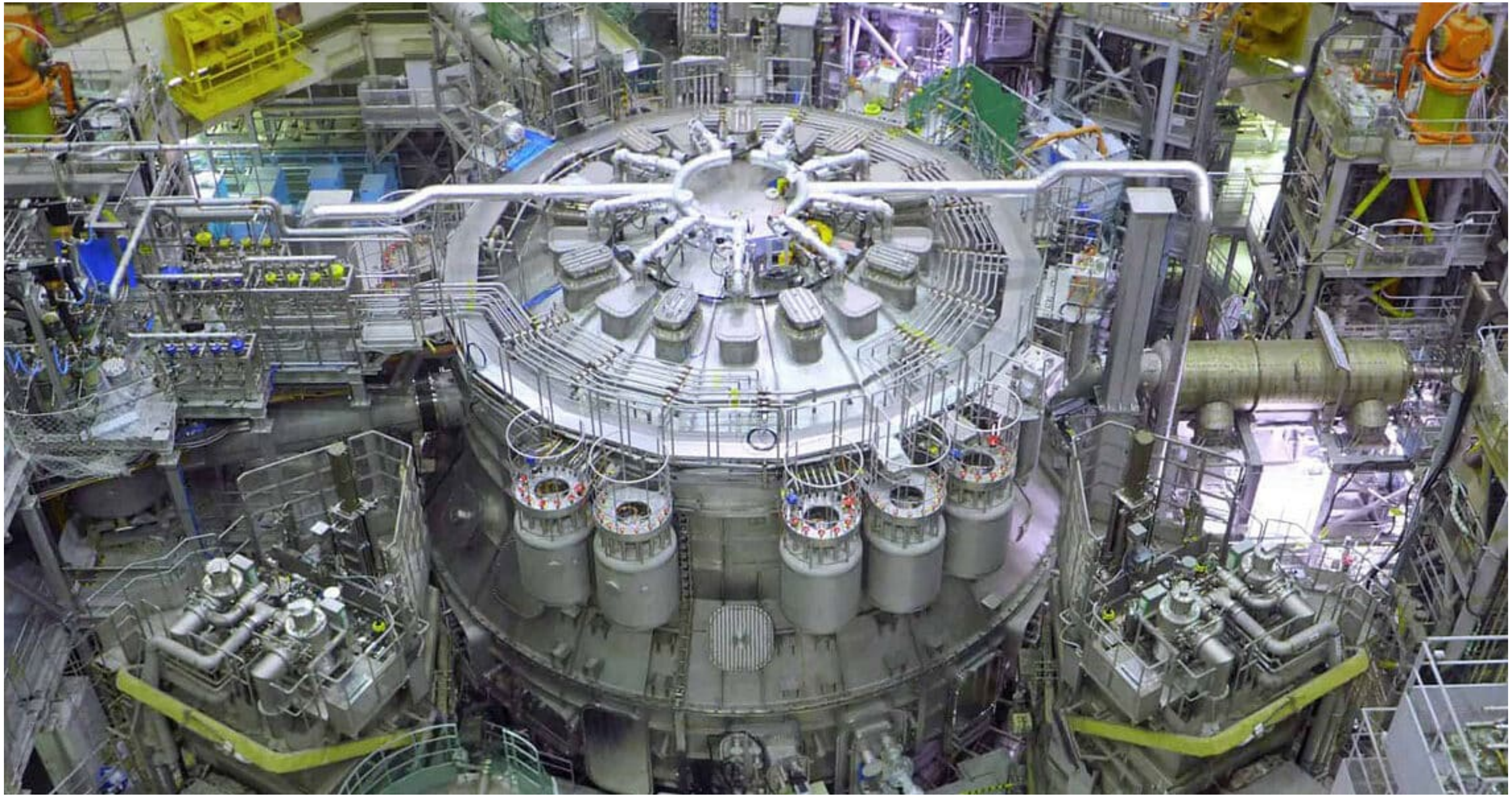
b) Zero magnetic field

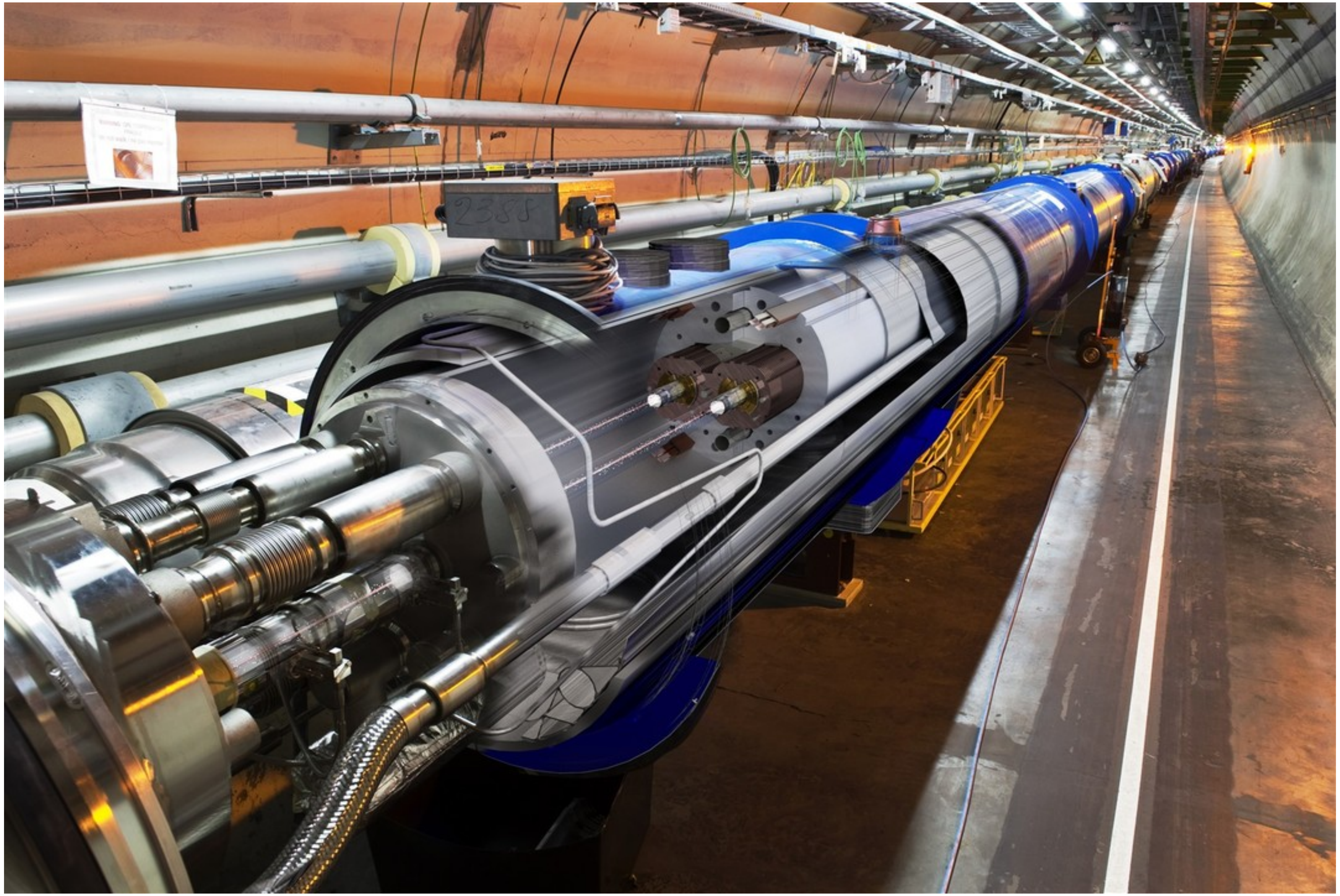
c) Both of the above

d) Neither of a) or b)









Large Hadron Collider

In a superconducting electromagnet, why do you think that wires of superconducting material are embedded in a thick copper matrix?

(a) The copper part helps in overcoming the mechanical stress from magnetic forces

(b) The copper part helps in conducting heat away from the superconductor

(c) The electric current passes through the copper part

(d) The copper acts as an insulating cover for the superconductor

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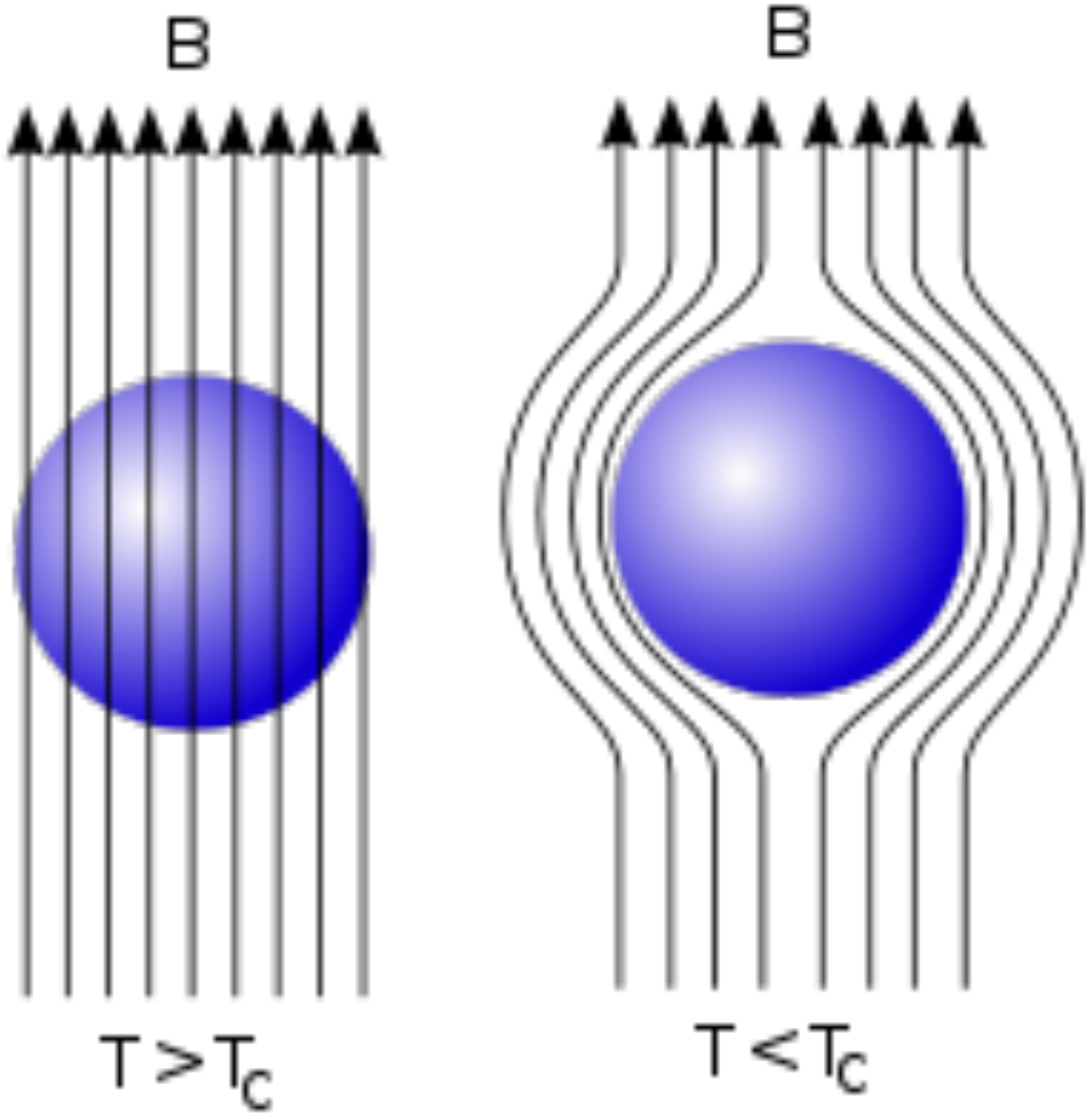
B
B
T > T_C
T < T_C