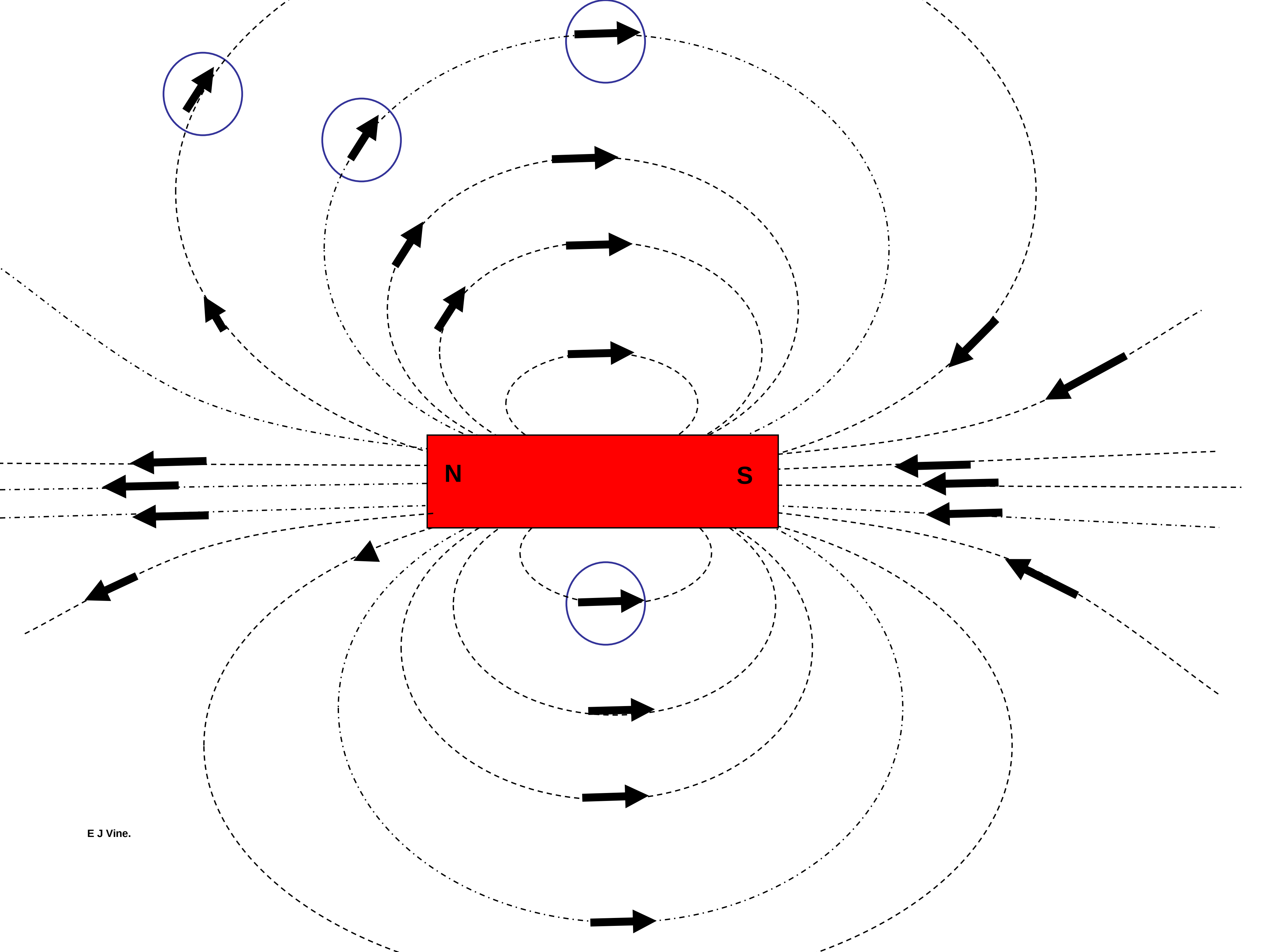
Electricity & Magnetism

UNIT – III **10 Periods**

Principles of Electro Magnetics and Electro-mechanics: Electricity and Magnetism - magnetic field and faraday's law - self and mutual inductance - Ampere's law - Magnetic circuit - Magnetic material and B-H Curve – Single phase transformer - principle of operation - EMF equation - voltage ratio - current ratio – KVA rating - Electromechanical energy conversion – Elementary generator and motors.


N
S
E J Vine.

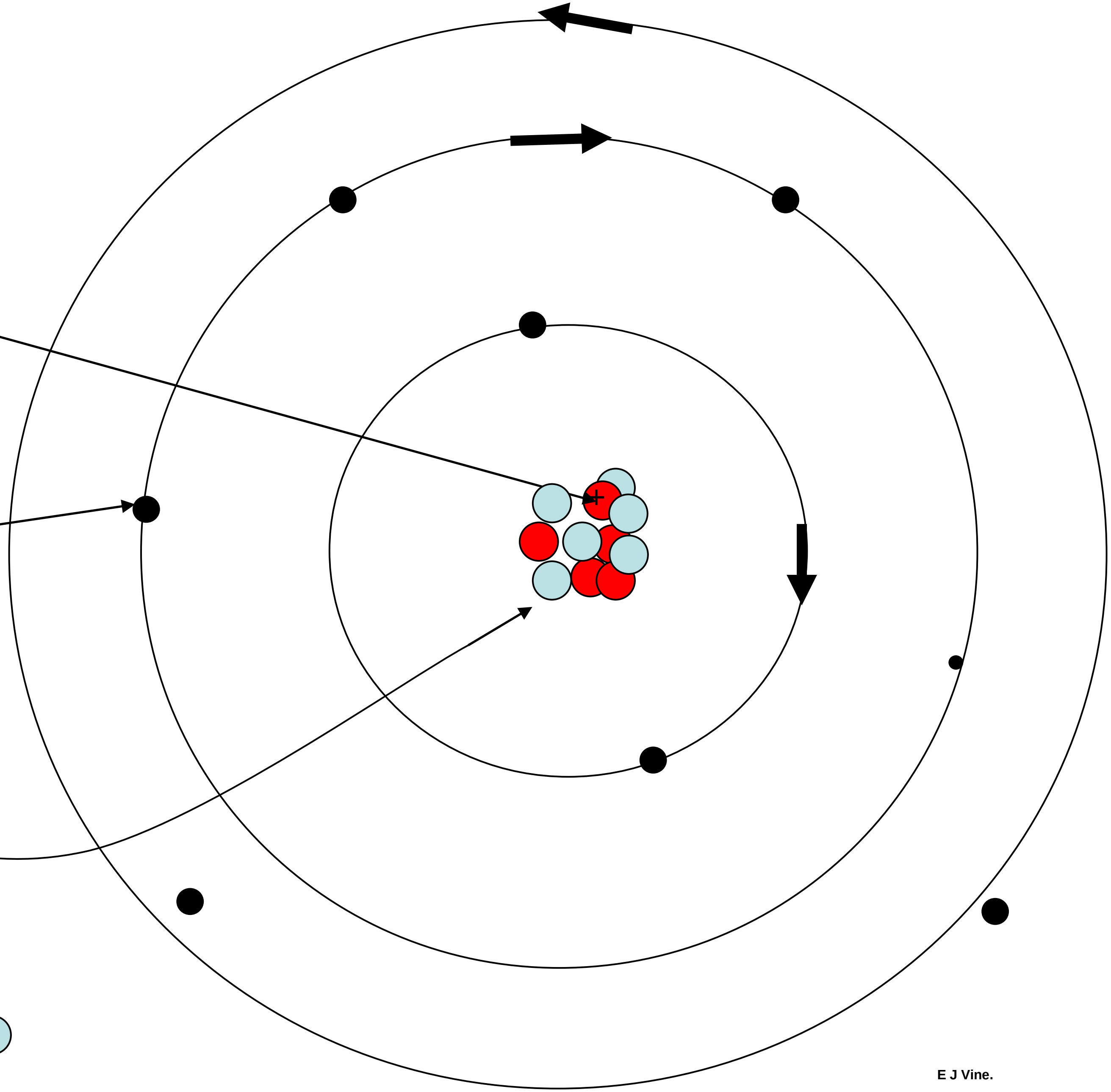
An Atom

Atoms have electrically charged particles inside.

The positive particles called PROTONS

ATTRACT the negative ones called ELECTRONS

This force of attraction keeps the electron in orbits around the centre of the atom called the NUCLEUS.



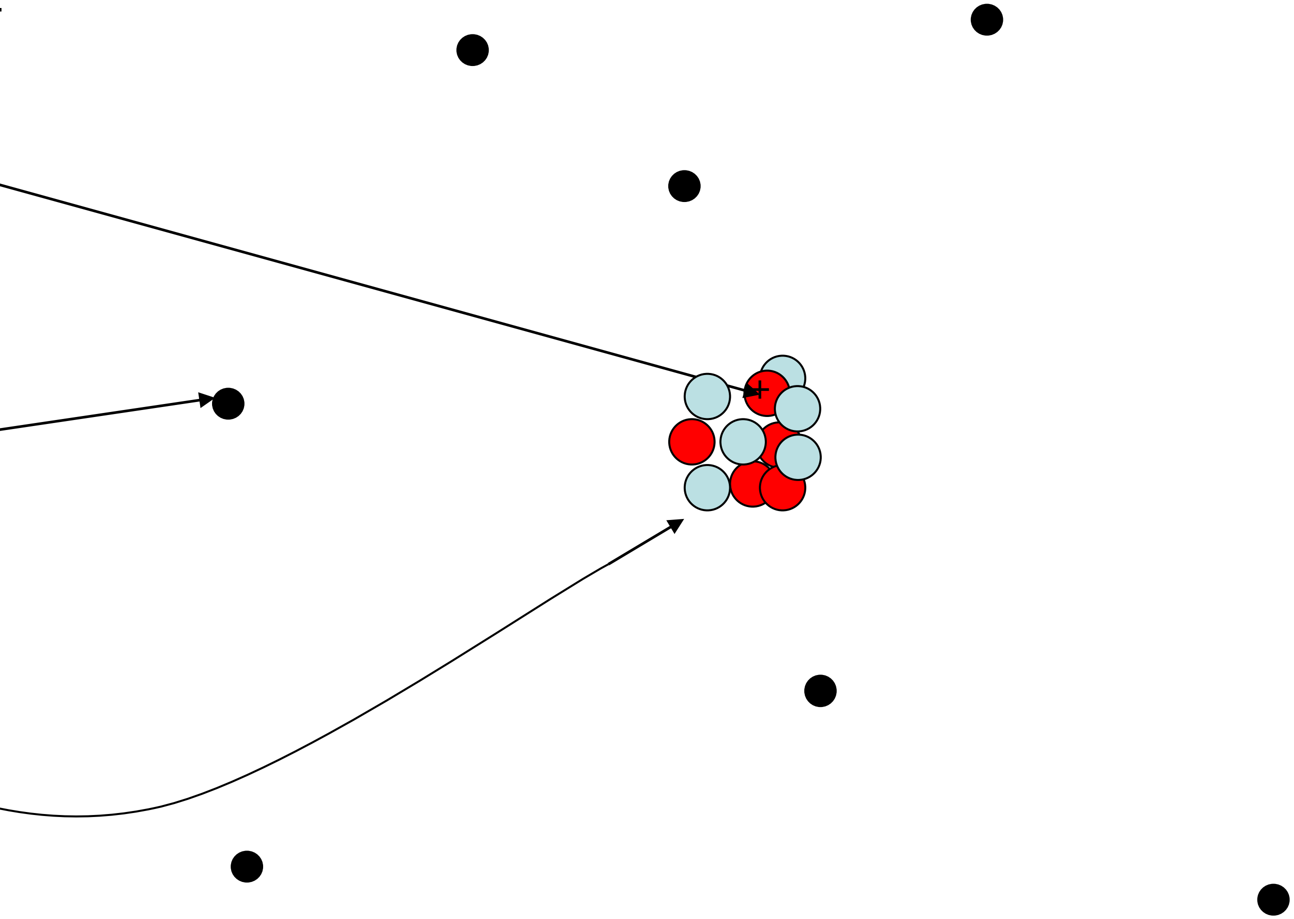
Neutrons have no electrical charge

E J Vine.

An Atom

Atoms have electrically charged particles inside.

The positive particles called PROTONS



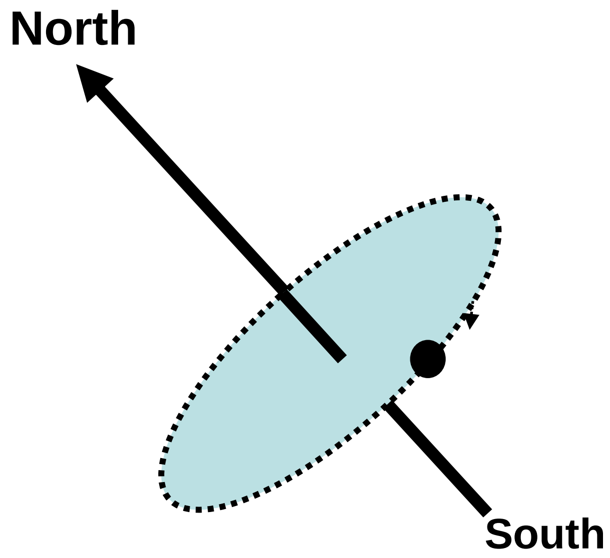
ATTRACT the negative ones called ELECTRONS

This force of attraction keeps the electron in orbits around the centre of the atom called the NUCLEUS.

Neutrons have no electrical charge

E J Vine.

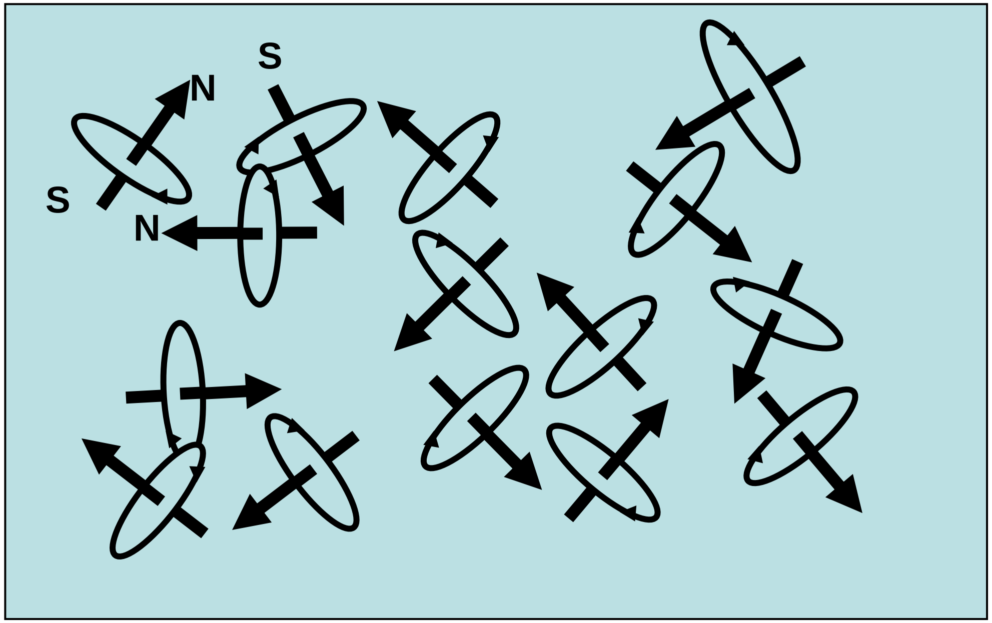
Atomic magnets



Electrons circling in atoms make the atoms behave like **tiny magnets**: This effect is very strong in iron

An iron or steel bar which has not been magnetised.

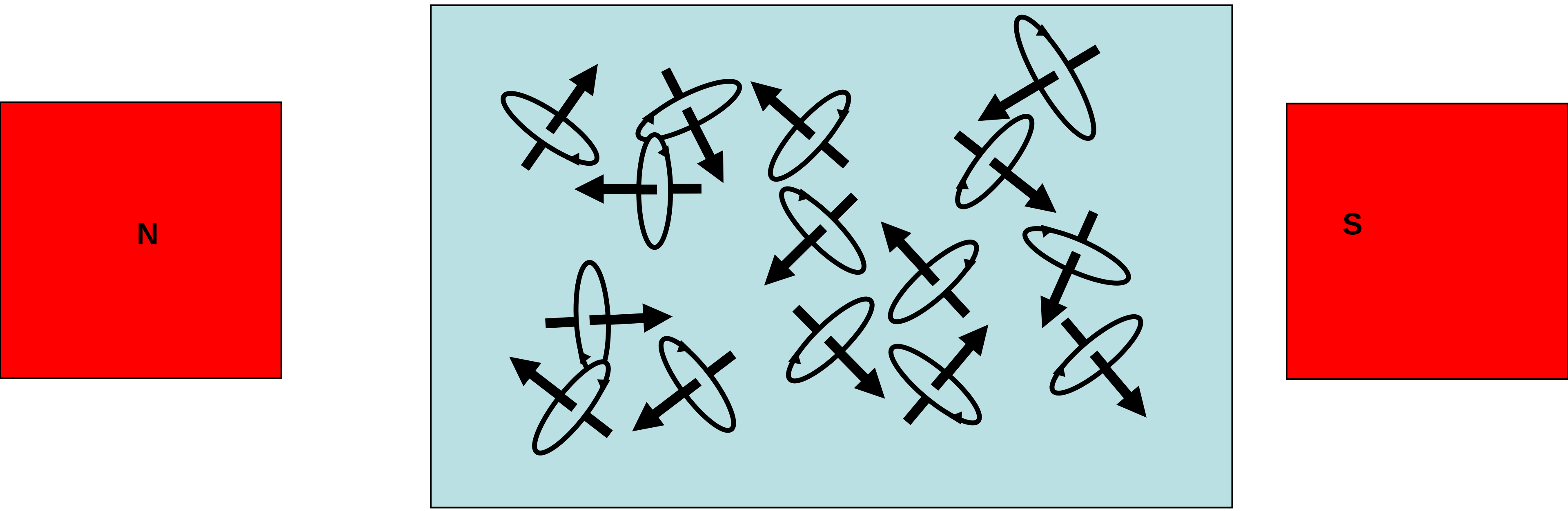
No magnetic force field



Atomic Magnets all jumbled pointing at each other: Their fields cancel each other and this iron or steel bar would not be magnetic

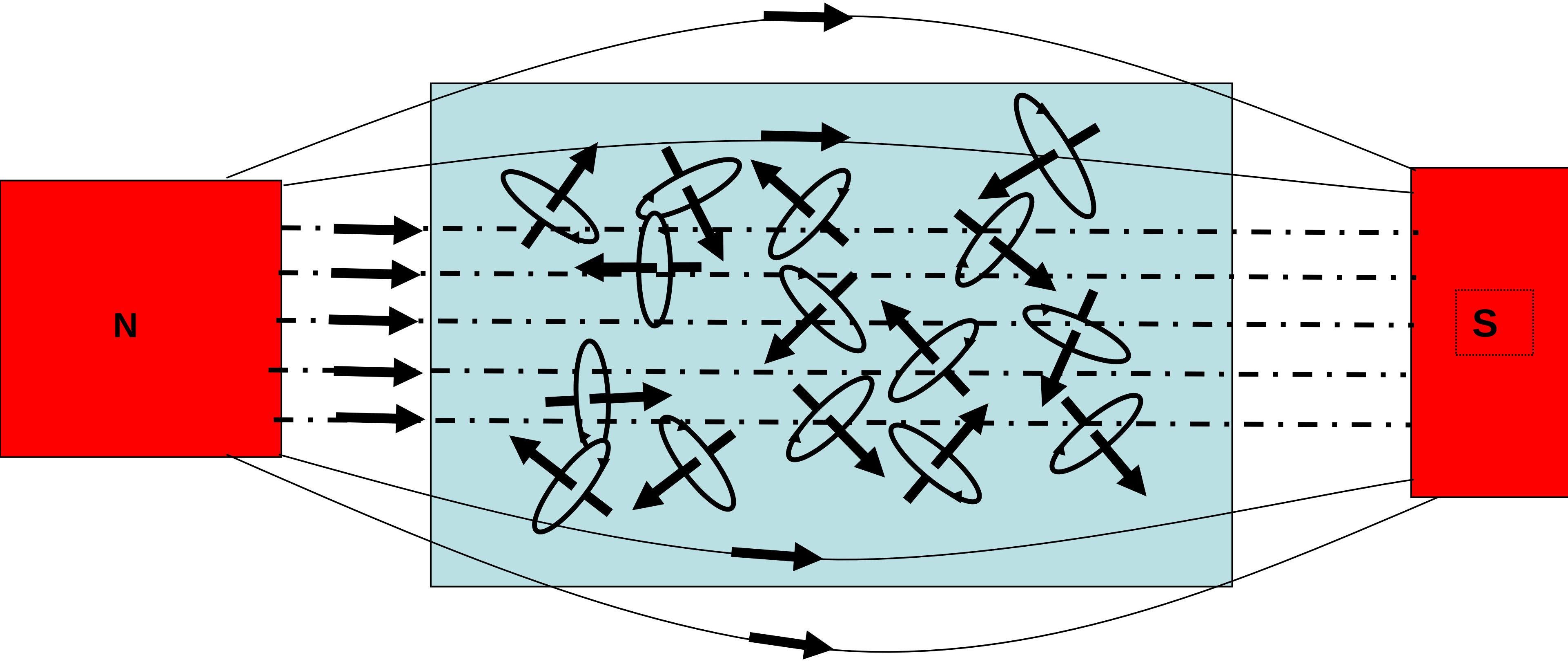
E J Vine.

Unmagentised steel or iron bar



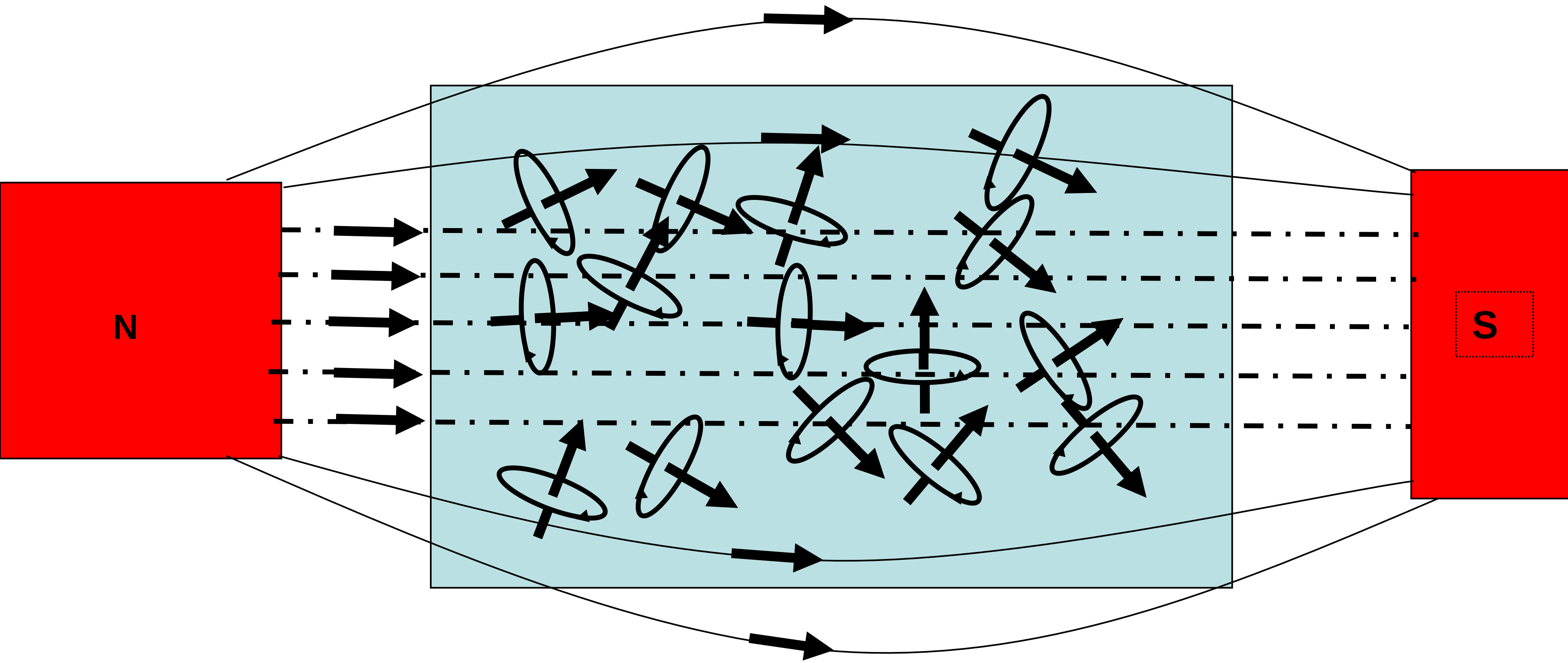
E J Vine.

The magnetic force field from the permanent magnets line up the atomic magnets and will make the steel or iron bar magnetic.



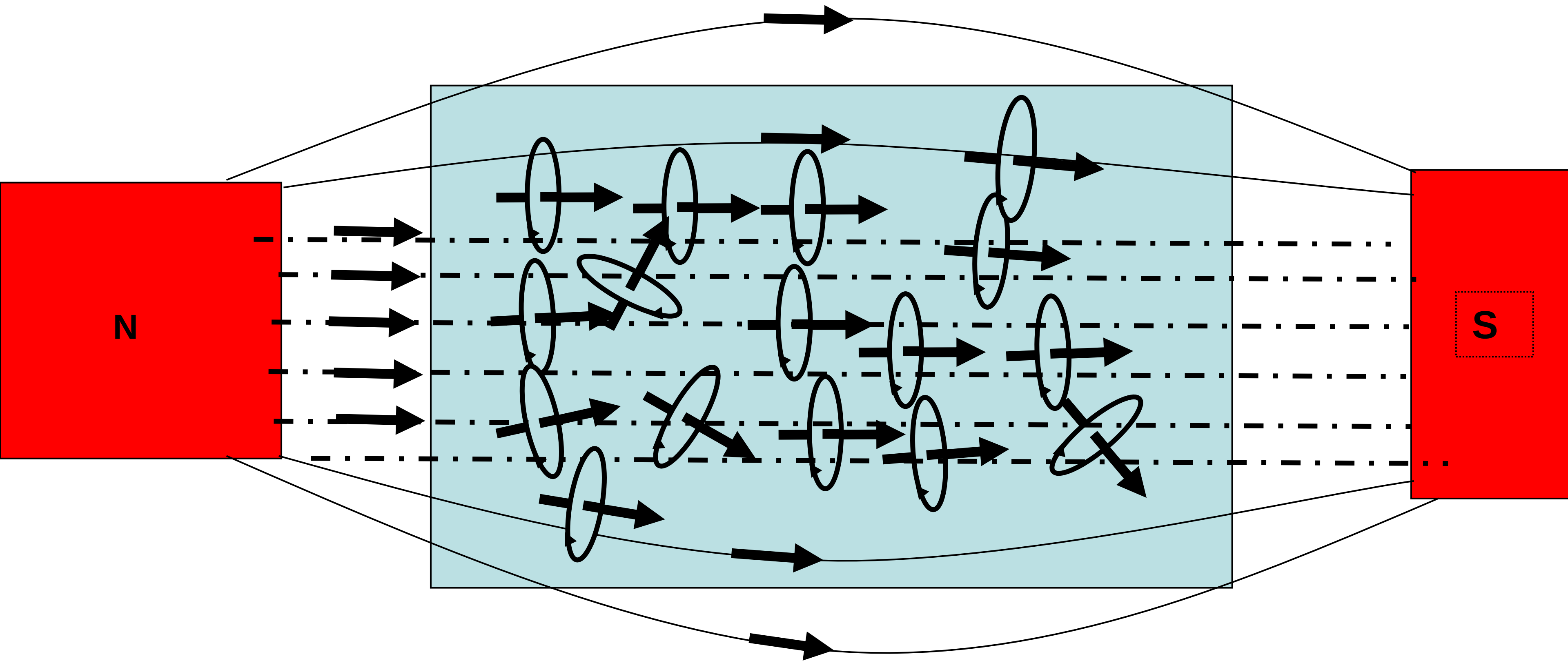
E J Vine.

The magnetic force field from the permanent magnets lines up the atomic magnets and will make the steel or iron bar magnetic.



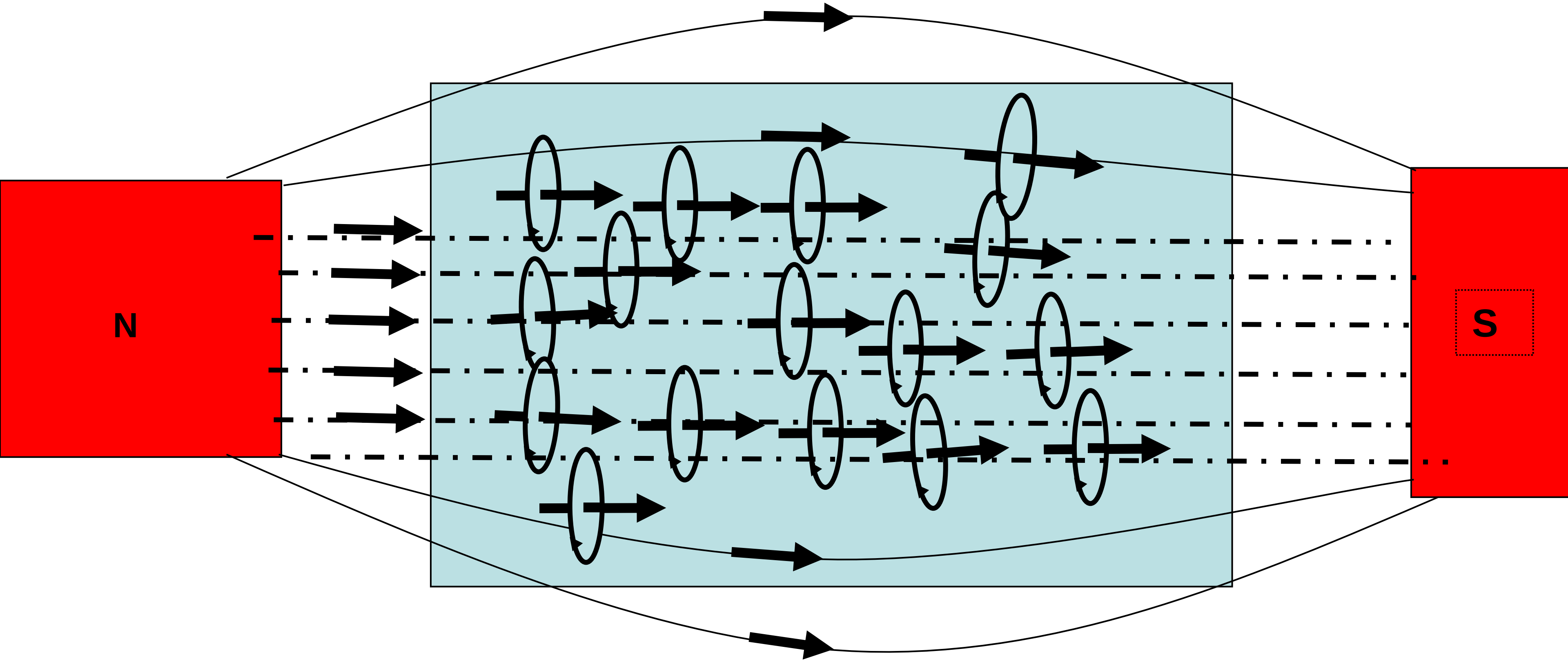
E J Vine.

The magnetic force field from the permanent magnets lines up the atomic magnets and will make the steel or iron bar magnetic.



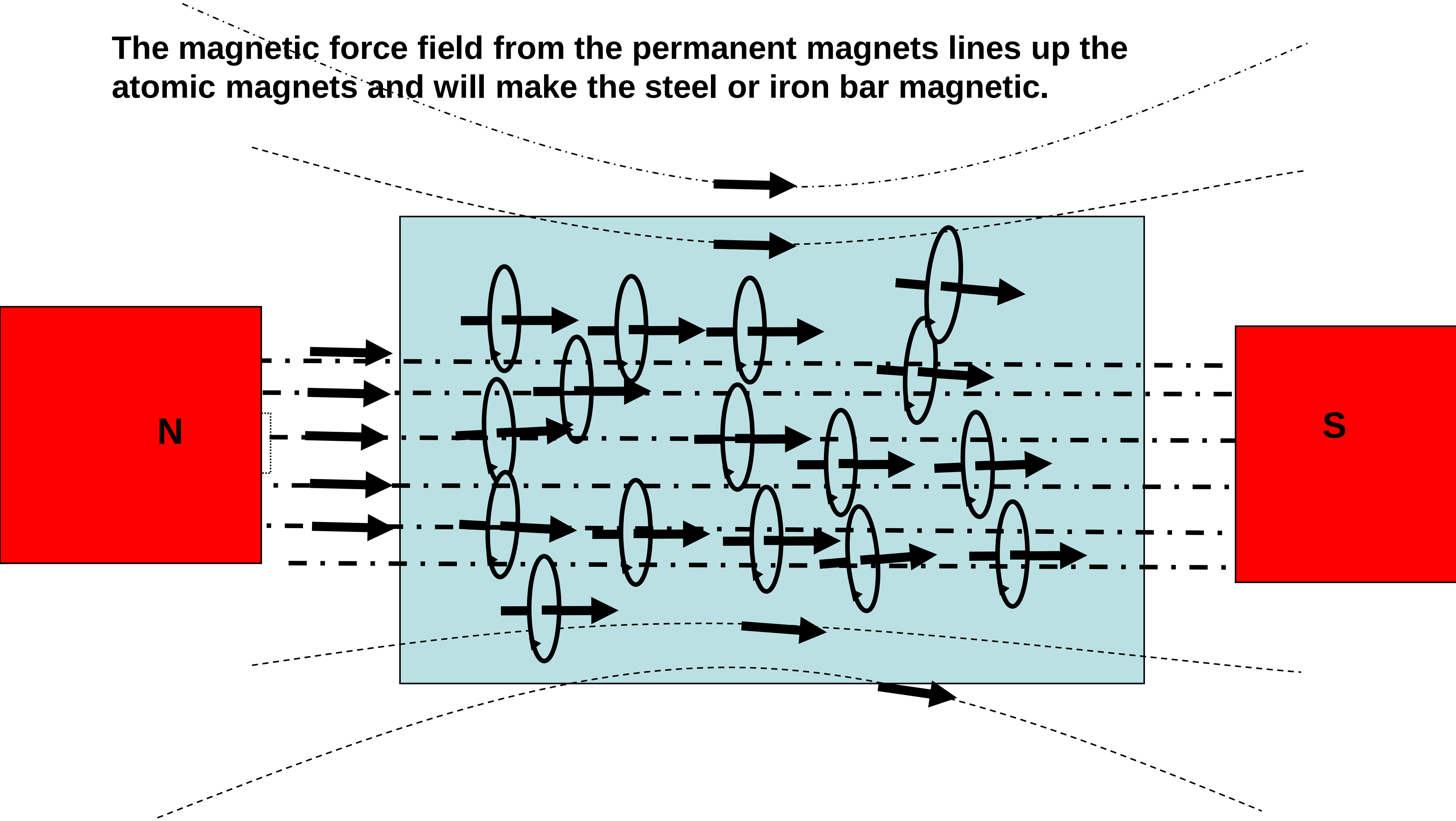
E J Vine.

The magnetic force field from the permanent magnets lines up the atomic magnets and will make the steel or iron bar magnetic.



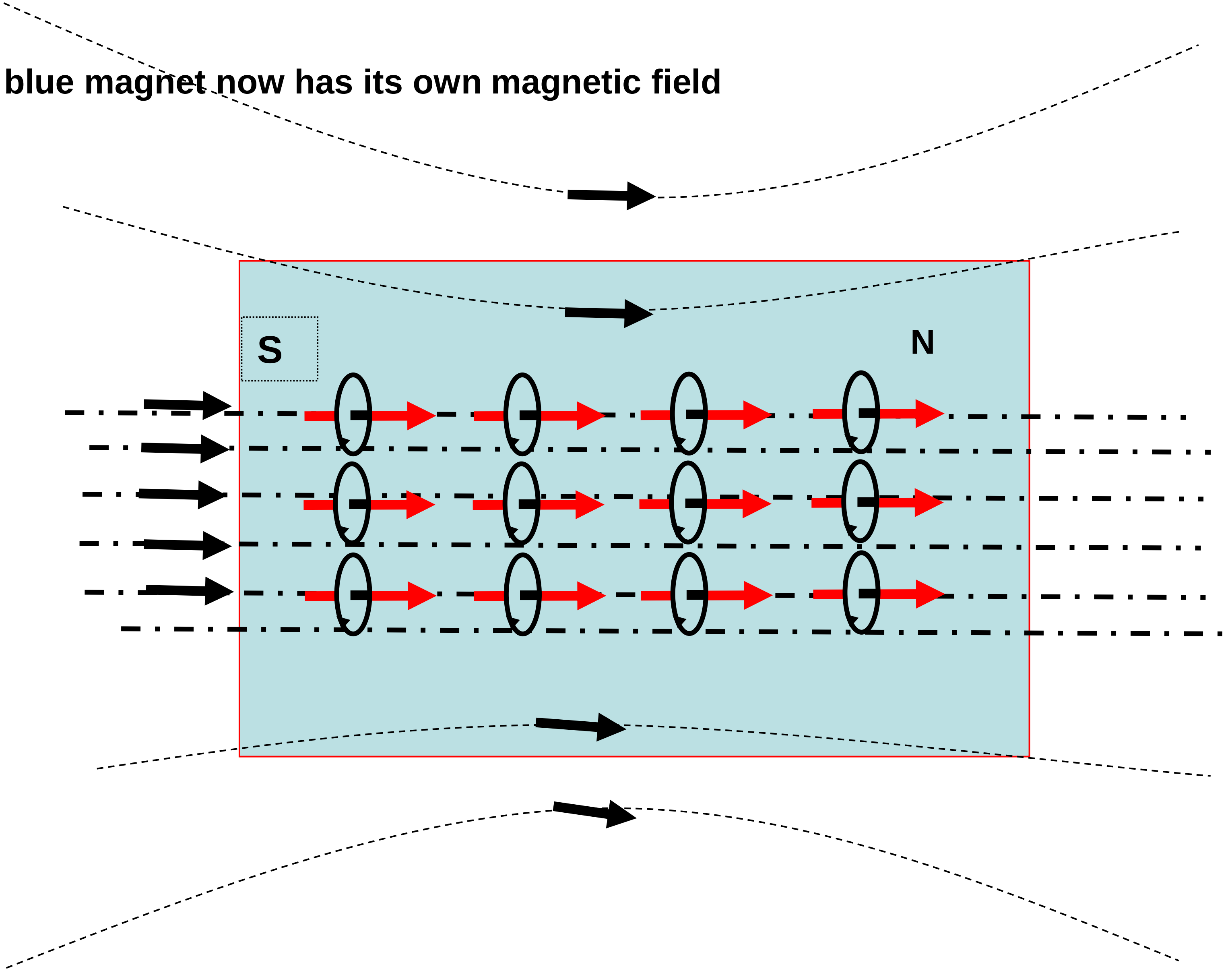
E J Vine.

The magnetic force field from the permanent magnets lines up the atomic magnets and will make the steel or iron bar magnetic.



E J Vine.

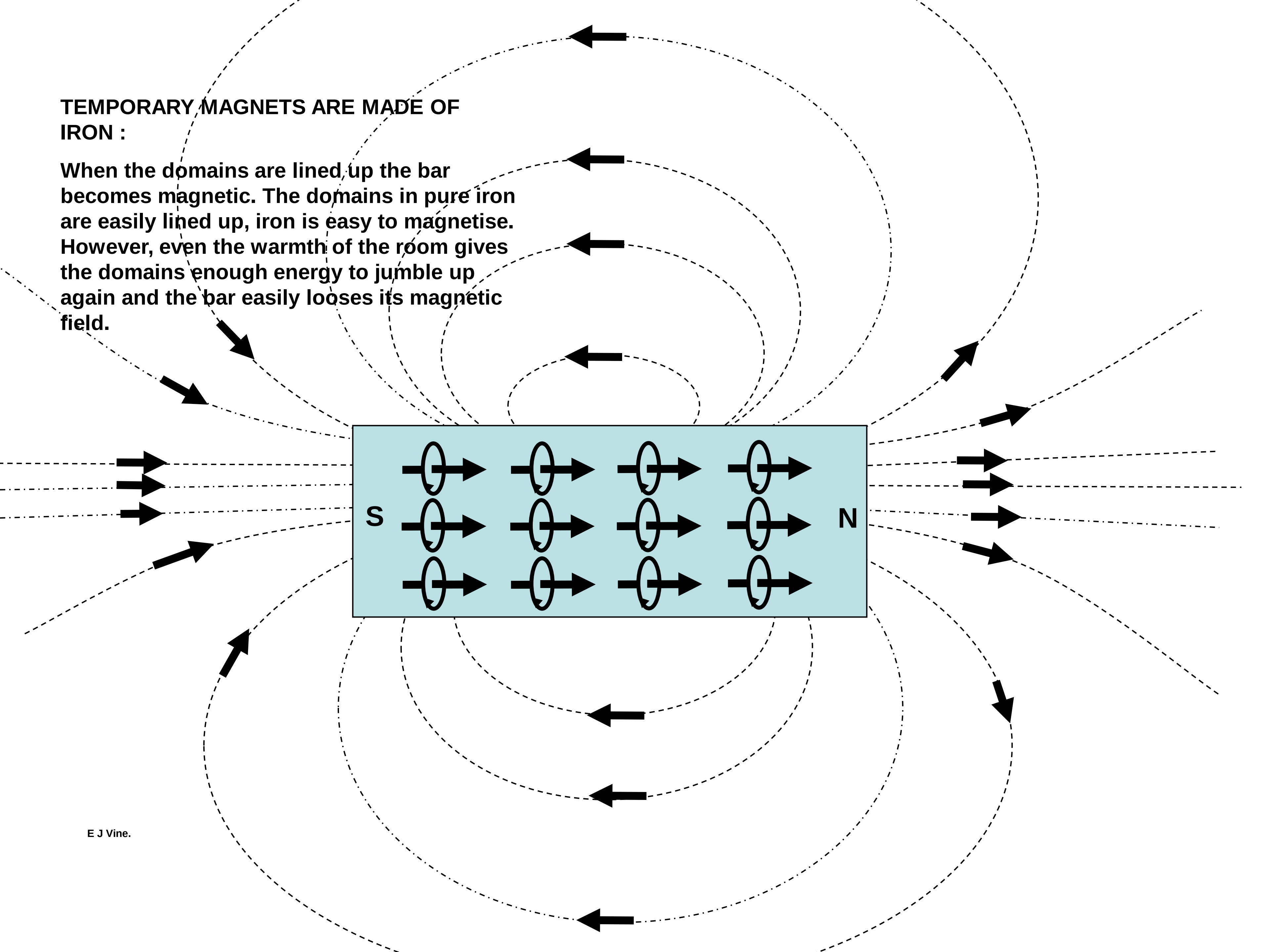
The blue magnet now has its own magnetic field



E J Vine.

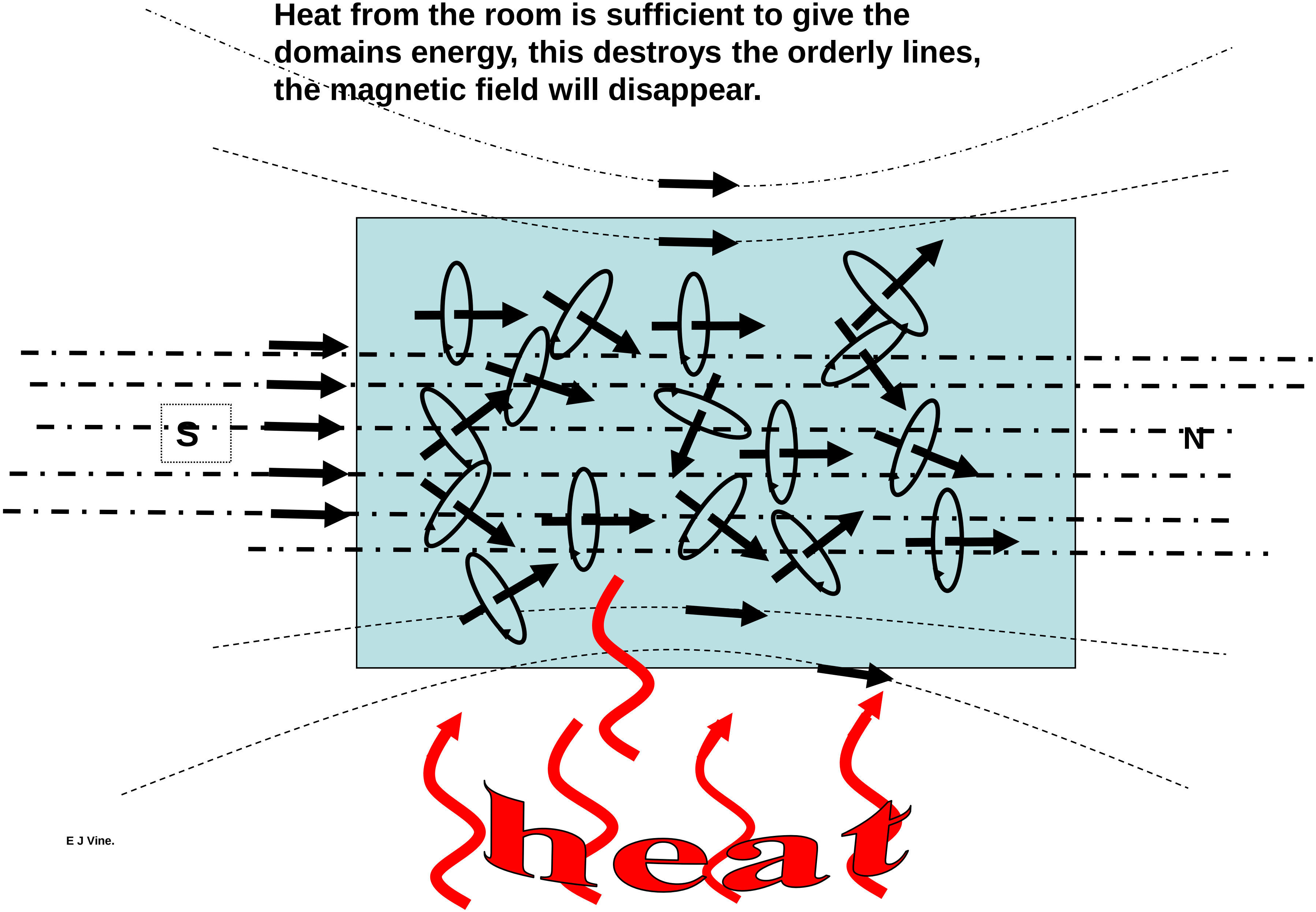
TEMPORARY MAGNETS ARE MADE OF IRON :

When the domains are lined up the bar becomes magnetic. The domains in pure iron are easily lined up, iron is easy to magnetise. However, even the warmth of the room gives the domains enough energy to jumble up again and the bar easily looses its magnetic field.



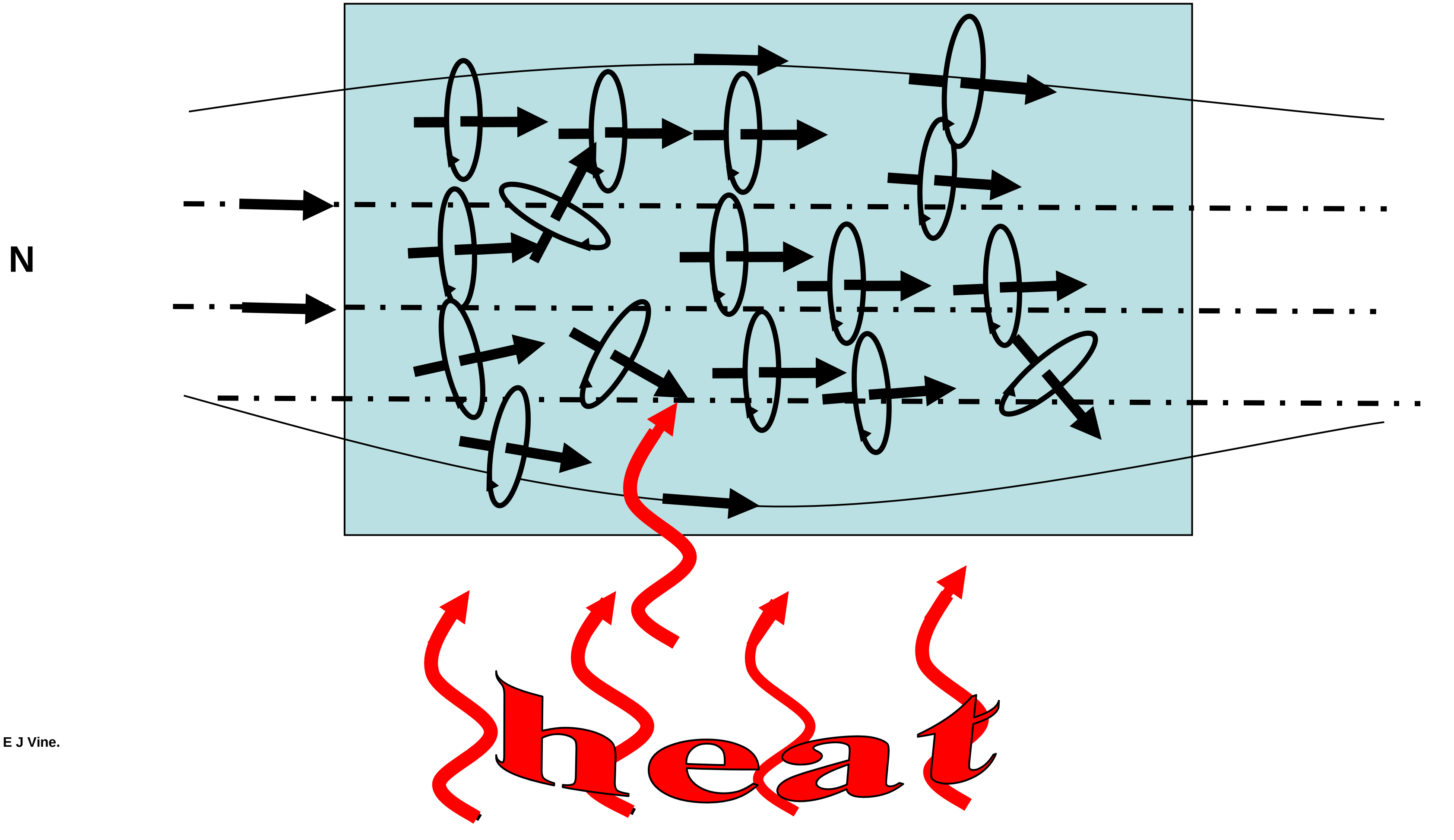
E J Vine.

Heat from the room is sufficient to give the domains energy, this destroys the orderly lines, the magnetic field will disappear.



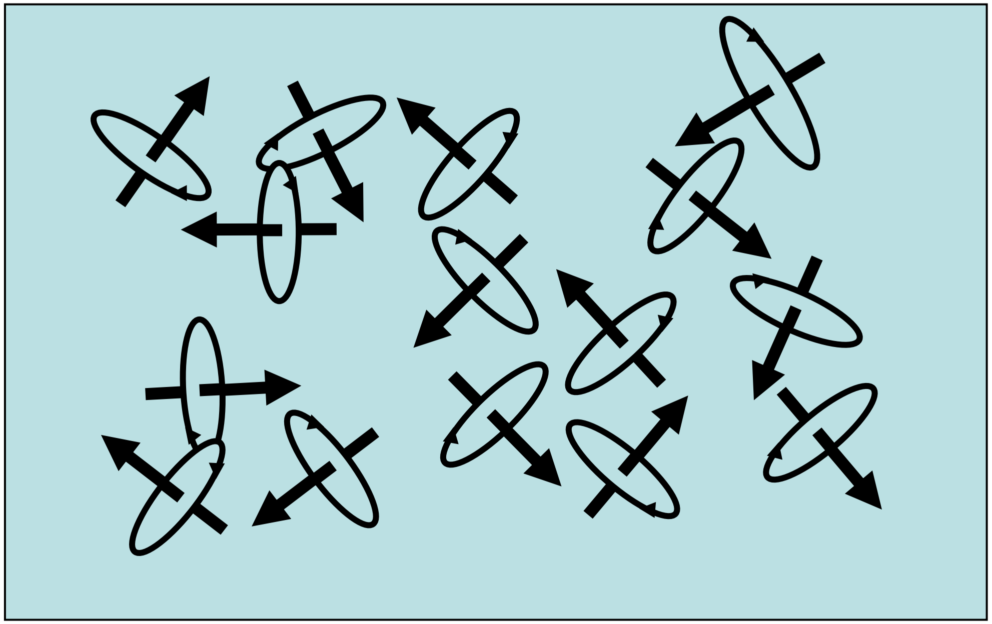
E J Vine.

The magnetic force field gradually disappears.

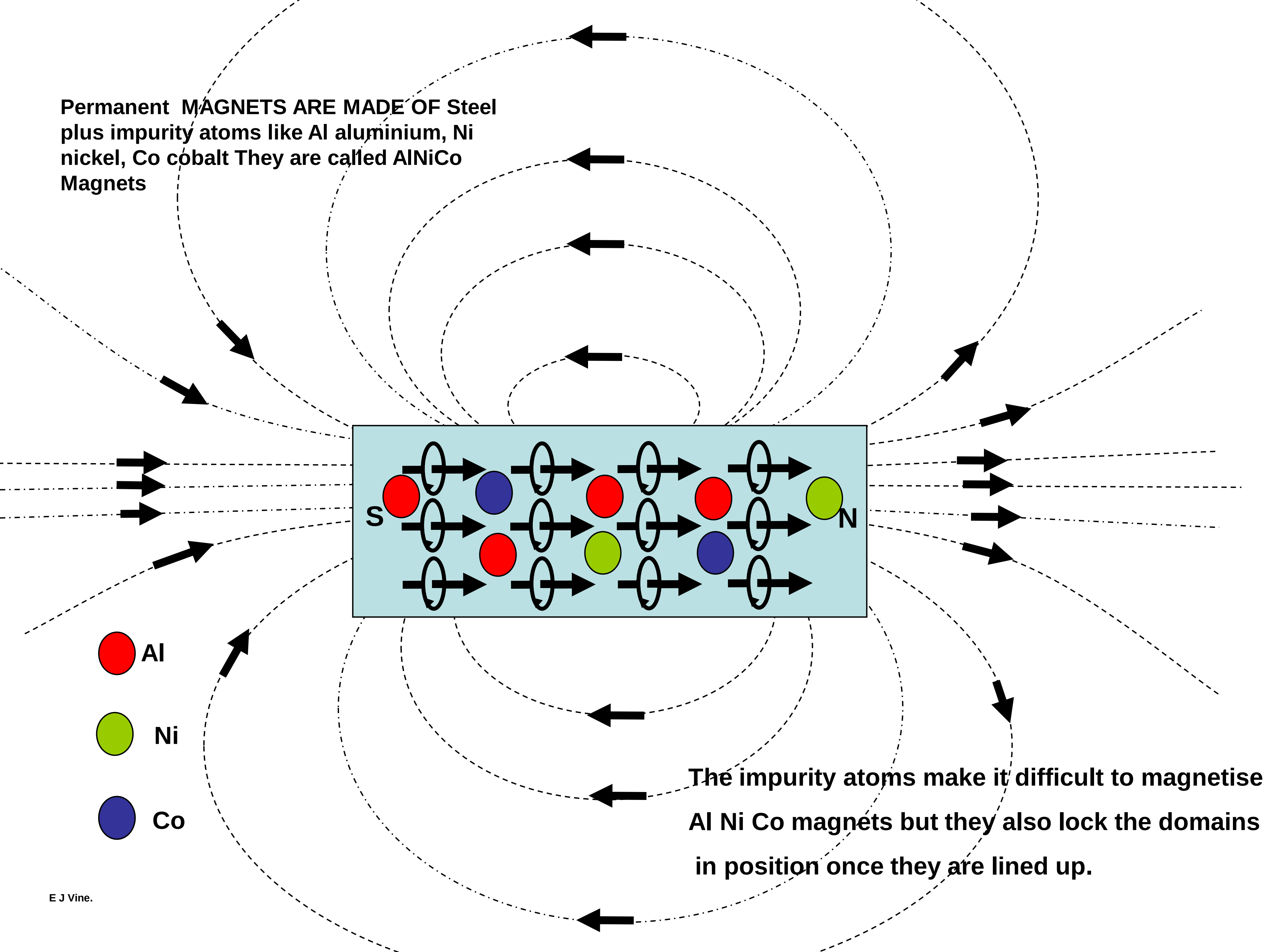


E J Vine.

No field left!!!!



E J Vine.



Permanent MAGNETS ARE MADE OF Steel plus impurity atoms like Al aluminium, Ni nickel, Co cobalt They are called AlNiCo Magnets
S
N
Al
Ni
Co
The impurity atoms make it difficult to magnetise Al Ni Co magnets but they also lock the domains in position once they are lined up.
E J Vine.

Big Numbers

- An electric current in a wire is actually a flow of electrons
- 1 Amp flowing through a bulb means that

 6,250,000,000,000,000,000 electrons

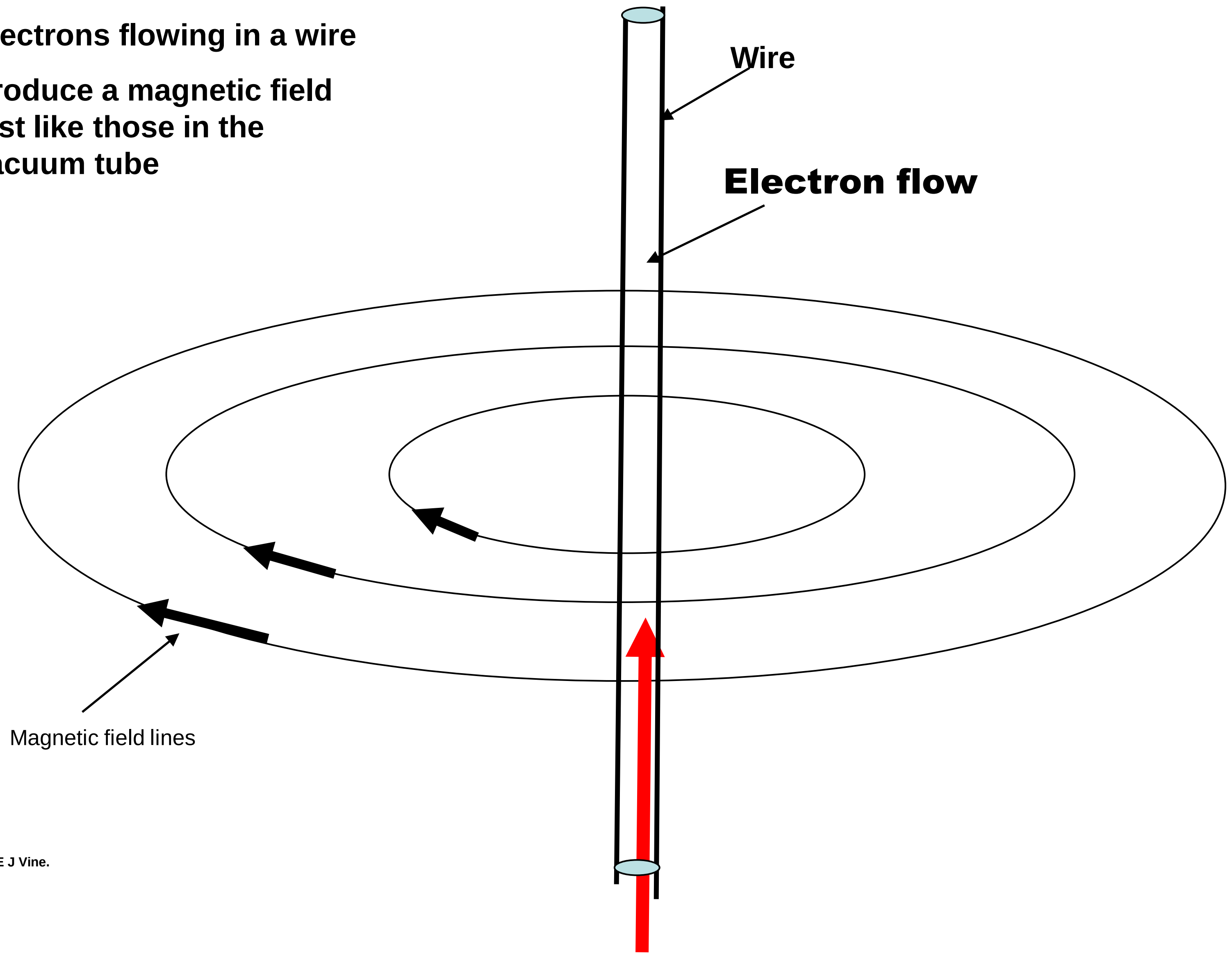
Pass through it every second!!!

1Amp =

6 ¼ million, million, million electrons per second

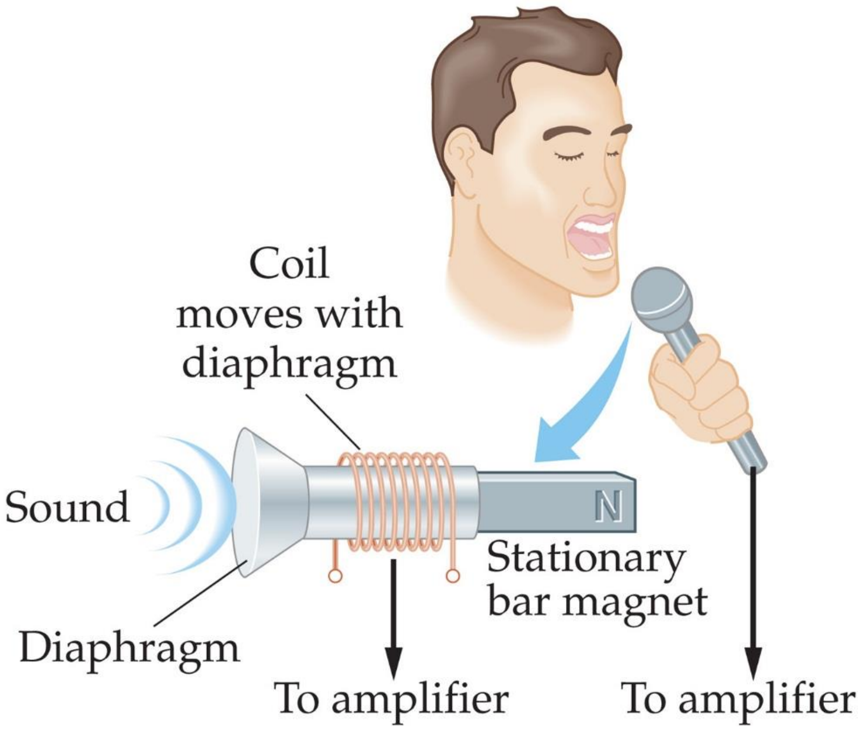
Electrons flowing in a wire

Produce a magnetic field just like those in the vacuum tube



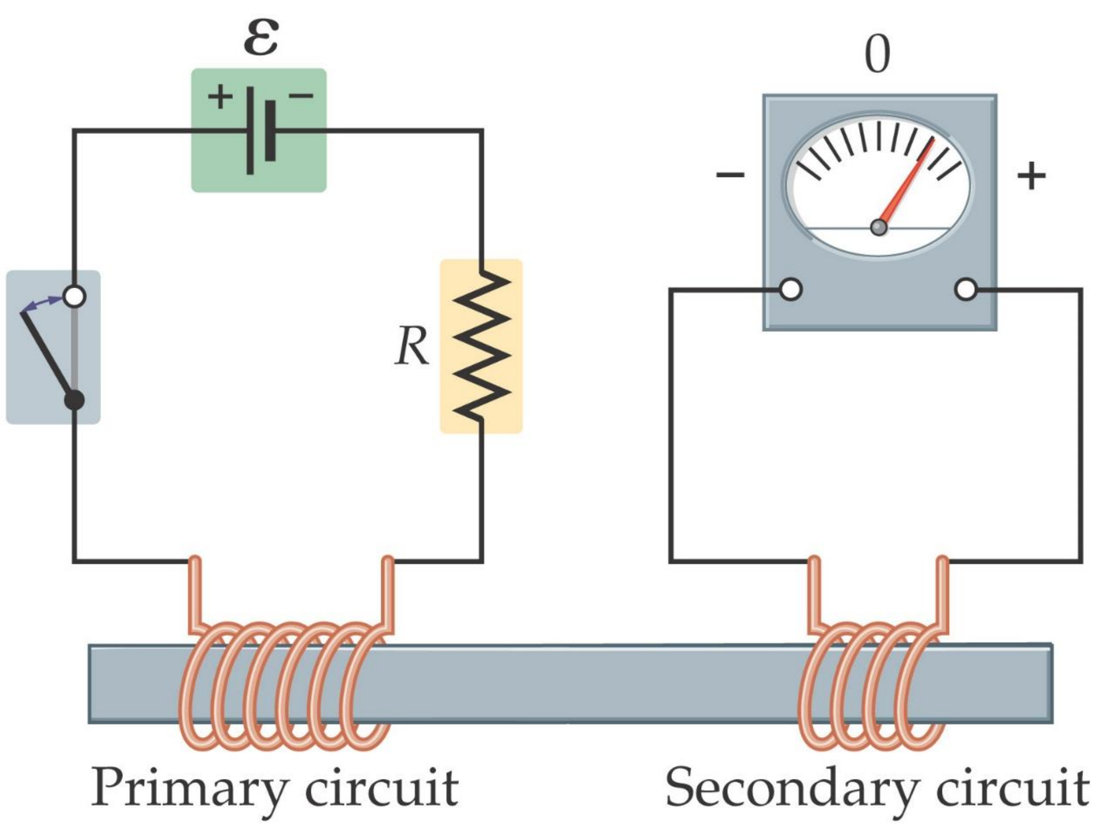
E J Vine.

Faraday’s Law of Induction



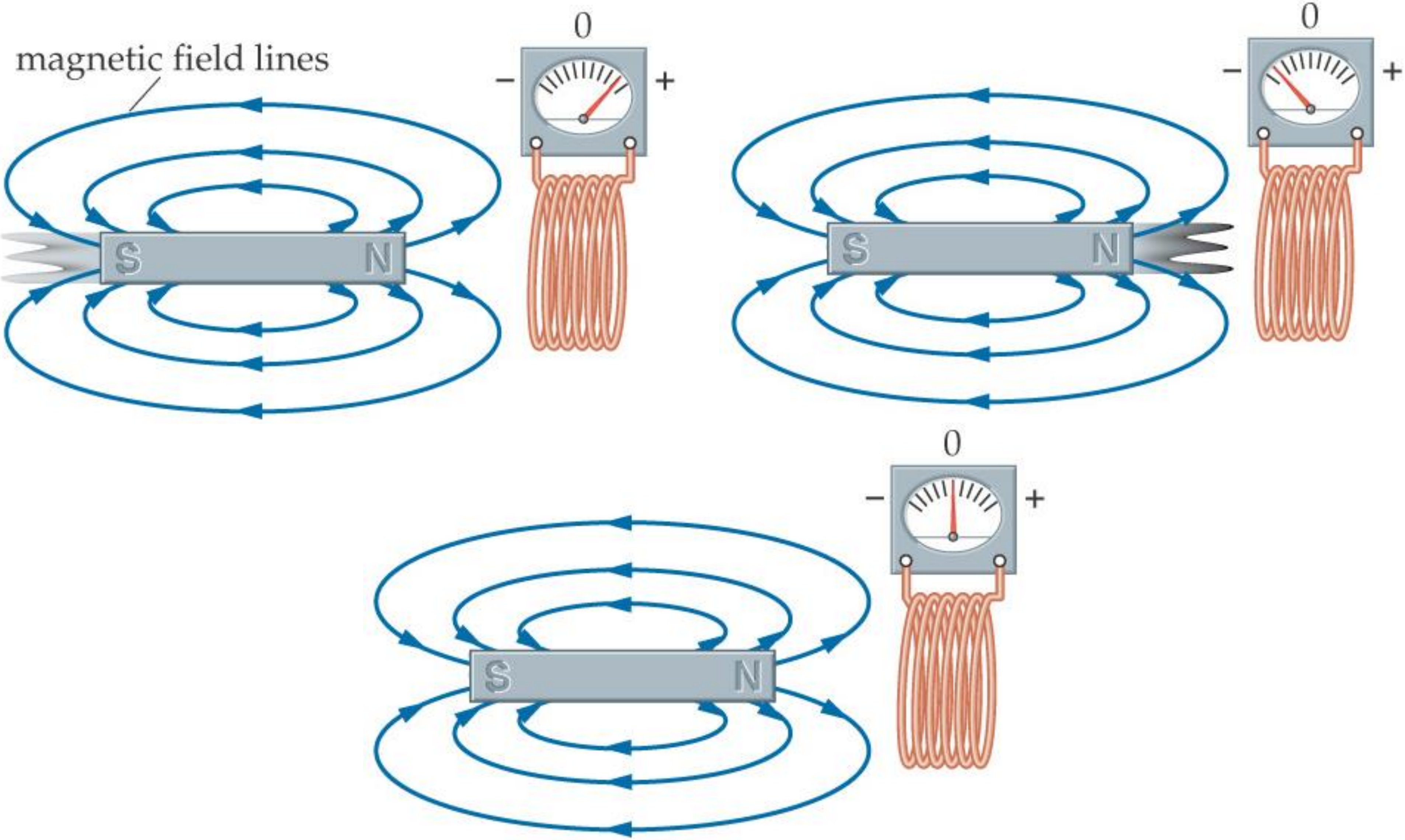
Induced Electromotive Force

Faraday's experiment: closing the switch in the primary circuit induces a current in the secondary circuit, but only while the current in the primary circuit is changing.



Induced Electromotive Force

Note the motion of the magnet in each image:



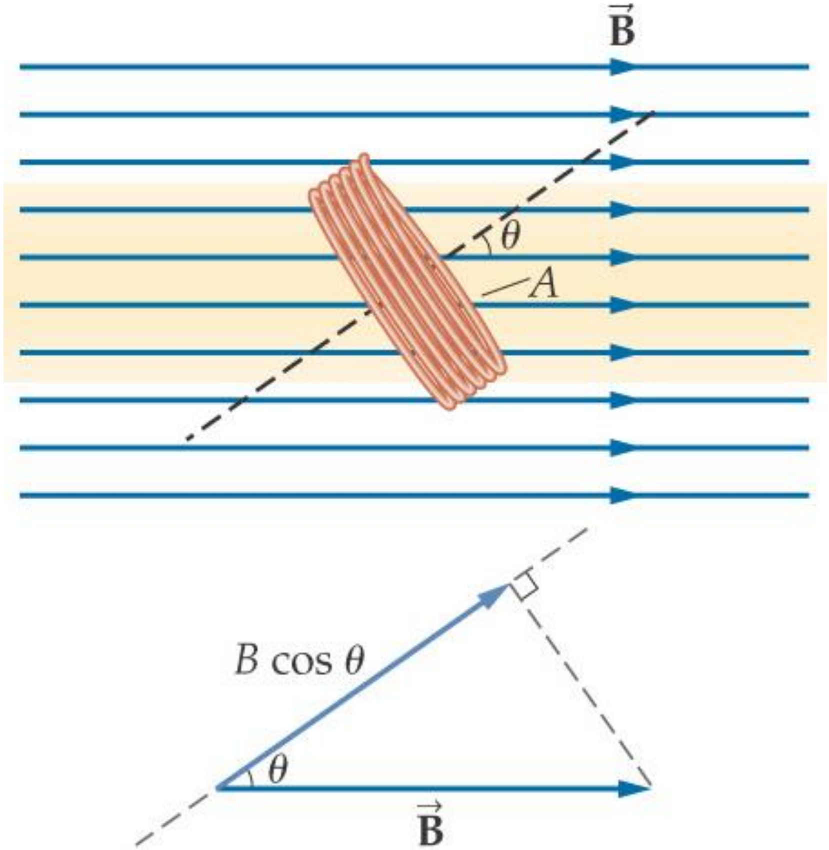
Magnetic Flux

Definition of Magnetic Flux, Φ

$$\Phi = (B\cos\theta)A = BA\cos\theta$$

SI unit: $1\ \mathrm{T\cdot m^2} = 1\ \text{weber} = 1\ \mathrm{Wb}$

Magnetic flux is used in the calculation of the induced emf.

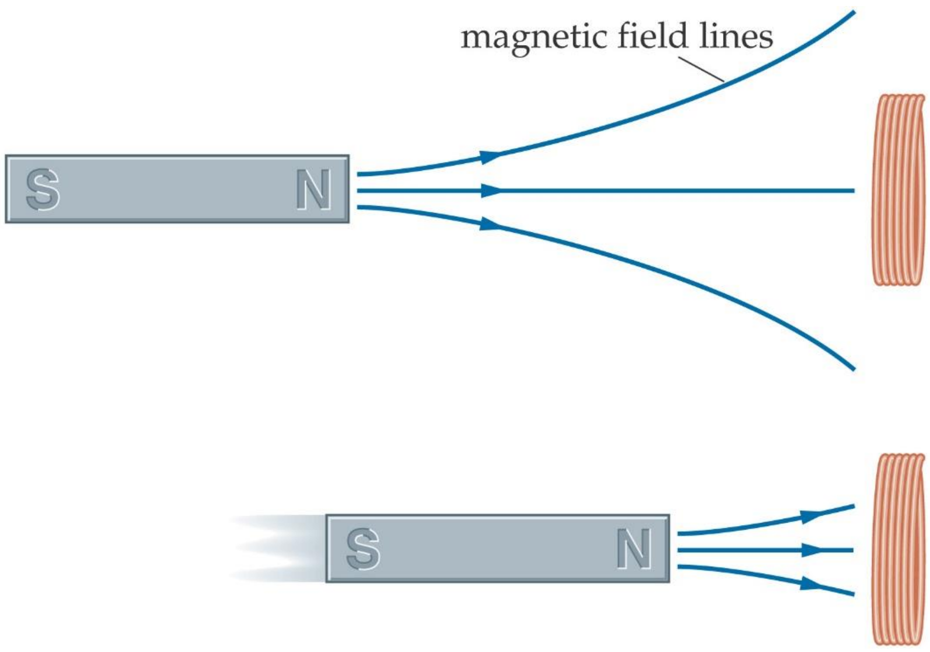


Faraday's Law of Induction

Faraday's law: An emf is induced only when the magnetic flux through a loop changes with time.

Faraday's Law of Induction

$$\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t} = -N\frac{\Phi_{\text{final}} - \Phi_{\text{initial}}}{t_{\text{final}} - t_{\text{initial}}}$$

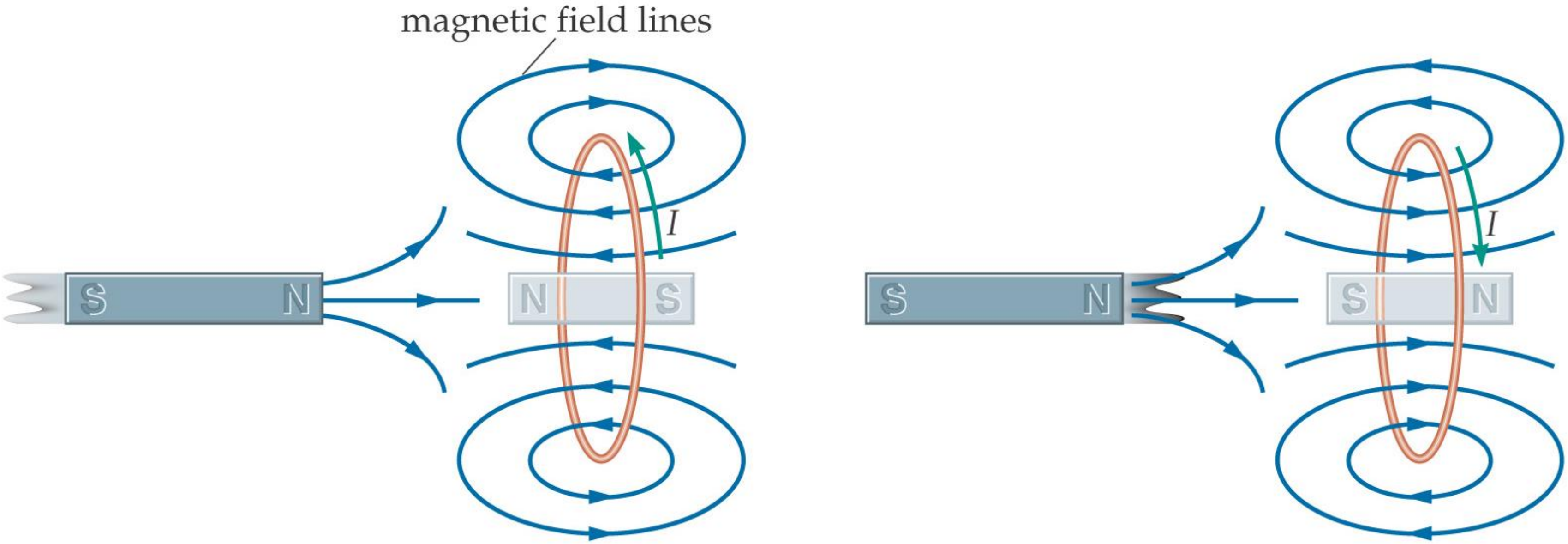


Lenz's Law

Lenz's Law

An induced current always flows in a direction that *opposes* the change that caused it.

Therefore, if the magnetic field is increasing, the magnetic field created by the induced current will be in the opposite direction; if decreasing, it will be in the same direction.



Inductance

Inductance is the proportionality constant that tells us how much emf will be induced for a given rate of change in current:

Definition of Inductance, *L*

$$|\mathcal{E}| = N\left|\frac{\Delta\Phi}{\Delta t}\right| = L\left|\frac{\Delta I}{\Delta t}\right|$$

SI unit: $1\ \mathrm{V}\cdot\mathrm{s/A} = 1\ \mathrm{henry} = 1\ \mathrm{H}$

Solving for L,

$$L = N\left|\frac{\Delta\Phi}{\Delta I}\right|$$

Inductance

Given the definition of inductance, the inductance of a solenoid can be calculated:

Inductance of a Solenoid

$$L = \mu_0 \left(\frac{N^2}{\ell} \right) A = \mu_0 n^2 A \ell$$

When used in a circuit, such a solenoid (or other coil) is called an inductor.

Magnetic Circuits

Introduction

- Unlike electric field lines, the lines of magnetic flux form *closed loops*.
- A ***magnetic circuit*** is a closed path followed by lines of magnetic flux.
- A copper wire, because of its high conductivity, confines the electric current within itself.
- Similarly, a ferromagnetic material (such as iron or steel), due to its high *permeability*, confines magnetic flux within itself.

Magnetostatics – Ampere’s Circuital Law

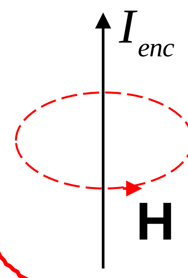
Likewise, in magneto static problems with sufficient symmetry we can employ *Ampere’s Circuital Law* more easily than the Law of Biot-Savart.

magnetic field intensity

Ampere’s Circuital Law says that the integration of **H** around any closed path is equal to the net current enclosed by that path.

Turns

$$\oint \mathbf{H} \cdot d\mathbf{L} = I_{enc} \Rightarrow H \cdot l = NI$$



The line integral of **H** around a closed path is termed the *circulation* of **H**.

$$\boxed{H = \frac{NI}{l}}$$

MMF

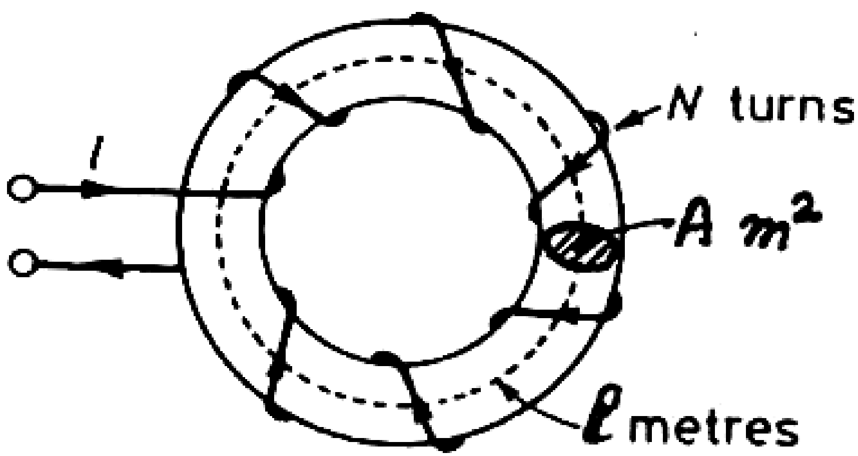
Magnetomotive Force (MMF) ⇔ EMF

- The electric current is due to the existence of an electromotive force (emf).
- By analogy, we may say that in a magnetic circuit, the magnetic flux is due to the existence of a ***magnetomotive force*** (***mmf***).
- mmf is caused by a current flowing through one or more turns.
- The value of the mmf is proportional to the current and the number of turns.
- It is expressed in *ampere turns* (At).
- But for the purpose of dimensional analysis, it is expressed in amperes.

Next

Magnetic Field Strength (*H*)

- *The mmf per metre length of the magnetic circuit* is termed as the ***magnetic field strength***, ***magnetic field intensity***, or ***magnetizing force***.
- It units are ampere-turns per metre (At/m) .
- Its value is independent of the medium .



MMF

$$H = \frac{\mathcal{F}}{l} = \frac{IN}{l}$$

Next

Magnetic Permeability (μ)

- If the core of the toroid is vacuum or air, the magnetic flux density *B* in the core bears a definite ratio to the magnetic field strength *H.*
- This ratio is called *permeability of free space*.
- Thus, for vacuum or air,

$$\frac{B}{H} = \mu_0 = 4\pi \times 10^{-7}\ \mathrm{Tm/A}$$

Next

Reluctance ($\mathcal{R}$) and Permeance ($\mathcal{G}$)

- The current in an electric circuit is limited by the presence of resistance of the electric circuit.
- Similarly, the flux Φ in a magnetic circuit is limited by the presence of the ***reluctance*** of the magnetic circuit,

$$\mathcal{R} = \frac{1}{\mu}\frac{l}{A} = \frac{1}{\mu_r \mu_0}\frac{l}{A}$$

The reciprocal of reluctance is known as ***permeance*** ($\mathcal{G}$).

Next

Magnetic Circuit Theory

- For a toroid, mmf, $\mathcal{F} = NI$ ampere-turns.
- Because of this mmf, a magnetic field of strength H is set up throughout the length l.
- Therefore, $\mathcal{F} = Hl$
- If, B is the flux density, total flux is given as

$$\Phi = B \times A$$

- Dividing, we get

Click

$$\frac{\Phi}{\mathcal{F}} = \frac{BA}{Hl} = \frac{B}{H}\frac{A}{l} = \mu\frac{A}{l} = \mu_r\mu_0\frac{A}{l} \quad \Rightarrow \quad \Phi = \frac{\mathcal{F}}{l/(\mu_r\mu_0 A)}$$

Next

Comparing this with $$I = \frac{E}{R}$$

We get $$\mathcal{R} = \frac{1}{\mu_r \mu_0} \frac{l}{A}$$

Next

Similarities

1. The closed path for magnetic flux is called a magnetic circuit.	1. The closed path for electric current is called an electric circuit.
2. Flux, $\phi = \dfrac{\text{m.m.f.}}{\text{reluctance}}$	2. Current, $I = \dfrac{\text{e.m.f.}}{\text{resistance}}$
3. m.m.f. (ampere-turns)	3. e.m.f. (volts)
4. Reluctance, $S = \dfrac{l}{a\mu_0\mu_r}$	4. Resistance, $R = \rho \dfrac{l}{a}$
5. Flux density, $B = \dfrac{\phi}{a}\,\text{Wb/m}^2$	5. Current density, $J = \dfrac{I}{a}\,\text{A/m}^2$
6. m.m.f. drop = $\phi\, S$	6. Voltage drop = $I\,R$
7. Magnetic intensity, $H = N\,I/l$	7. Electric intensity, $E = V/d$
8. Permeance	8. Conductance.
9. Permeability	9. Conductivity

Dissimilarities

1. Truly speaking, magnetic flux does not flow.	1. The electric current acutally flows in an electric circuit.
2. There is no magnetic insulator. For example, flux can be set up even in air (the best known magnetic insulator) with reasonable m.m.f.	2. There are a number of electric insulators. For instance, air is a very good insulator and current cannot pass through it.

Example 1

- Calculate the magnetomotive force (mmf) required to produce a flux of 0.015 Wb across an air gap of 2.5 mm long, having an effective area of 200 cm^2.

Solution :

$$B = \frac{\Phi}{A} = \frac{0.015}{200 \times 10^{-4}} = 0.75 \text{ T}$$

$$H = \frac{B}{\mu_0} = \frac{0.75}{4\pi \times 10^{-7}} = 597\,000 \text{ A/m}$$

$$\mathcal{F} = Hl = 597\,000 \times 2.5 \times 10^{-3} = \mathbf{1492\ At}$$

Next

1) The flux produced in the air gap between two electromagnetic poles is 5 × 10^–2 wb. If the cross sectional area of the air gap is 0.2 m^2 find (a) flux density, (b) magnetic field intensity, (c) reluctance, and (d) permeance of the air gap. Find also the mmf dropped in the air gap given the length of the air gap to be 1.2 cm.

$\phi = 5\times10^{-2}$ wb

$a = 0.2\,m^2$

$l = 1.2$ cm.

(a) $B = \dfrac{\phi}{A}$

$= \dfrac{5\times10^{-2}}{0.2}$

$\boxed{B = 0.25\ T}$

(b) $H = \dfrac{B}{\mu_0}$

$H = \dfrac{0.25}{4\pi\times10^{-7}}$

$\boxed{H = 1.99\times10^{5}\ A/m}$

(c) $\mathcal{R} = \dfrac{l}{\mu_0 \times a}$

$= \dfrac{1.2\times10^{-2}}{4\pi\times10^{-7}\times 0.2}$

$\boxed{\mathcal{R} = 0.477\times10^{5}\ A/wb}$

S

(d) $P = \dfrac{1}{\mathcal{R}} = \dfrac{1}{S}$

$\boxed{P = 2.093\times10^{-5}\ wb/A}$

(e) $MMF = \phi \times \mathcal{R}$.

$= 5\times10^{-2}\times 0.477\times10^{5}$

$\boxed{MMF = 2385\ A}$

A ring has mean diameter of 15 cm, a cross section of 1.7 cm^2 and has a radial gap of 0.5 mm in it. It is uniformly wound with 1500 turns of insulated wire and a current of 1 A produces a flux of 0.1 mwb across the gap. Calculate the relative permeability of iron on the assumption that there is no magnetic leakage.

Exercise

Summary

- Electromagnetics
- Induction
- Faradyas Laws
- Lenz law
- Magnetic Circuits