Chapter 7
Electrical Machines

DC Machine

3-phase Induction Motor

Synchronous Machine (Alternator)

DC Machine
Day 32

Basic Principle

DC Machine

- Direct current (DC) machine applications in industry
  - Chemical plants
  - metallurgical plants
  - welding shops
  - traction
  - control
- Low and medium power applications
- Easy and simple control

DC Machine

Like all other electrical rotating machines

- DC machines are electromechanical devices
- Convert mechanical energy to electrical energy or vice versa
- The former is called electric generator
- While the second type is called electric motor

In most cases, the operation is reversible, that is, the same machine can be used as a generator or as a motor

DC Generator

Faraday's laws of electromagnetic induction

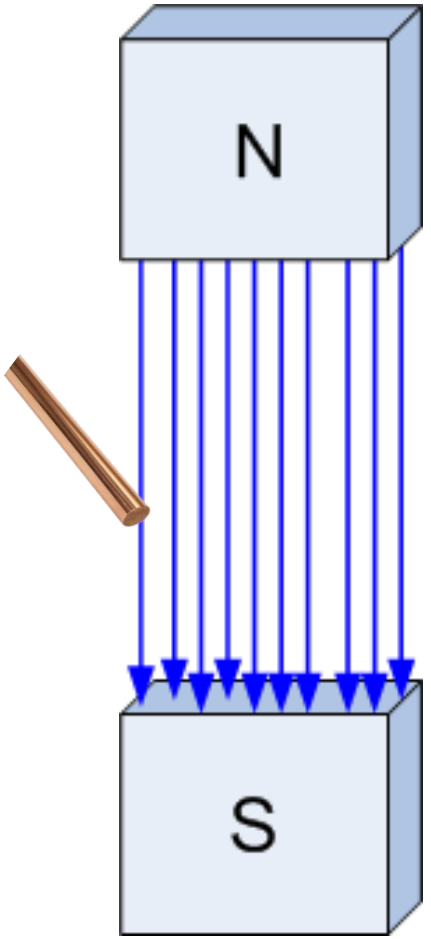
- An electromotive force (EMF) is induced across the two ends of a conductor
- When there is a relative motion between the conductor and a magnetic field linking with the conductor
- The amount of EMF induced is proportional to the rate of change of flux linking with the conductor
- According to Lenz's law, this EMF is induced in such a direction that it opposes the change in flux linking with the conductor

DC generators fall in which class?

- ways in which it is possible to have a relative motion between the conductor and the flux
  - ***Dynamically induced** EMF*
    - The conductor remains stationary, but the flux (or the magnet) physically moves
    - The flux (or the magnet) remains stationary, but the conductor physically moves
  - ***Statically induced** EMF*
    - The conductor as well as the magnet (or flux), both are physically stationary, but there is a relative motion between the two due to the fact that the flux is not constant, but varies with time.

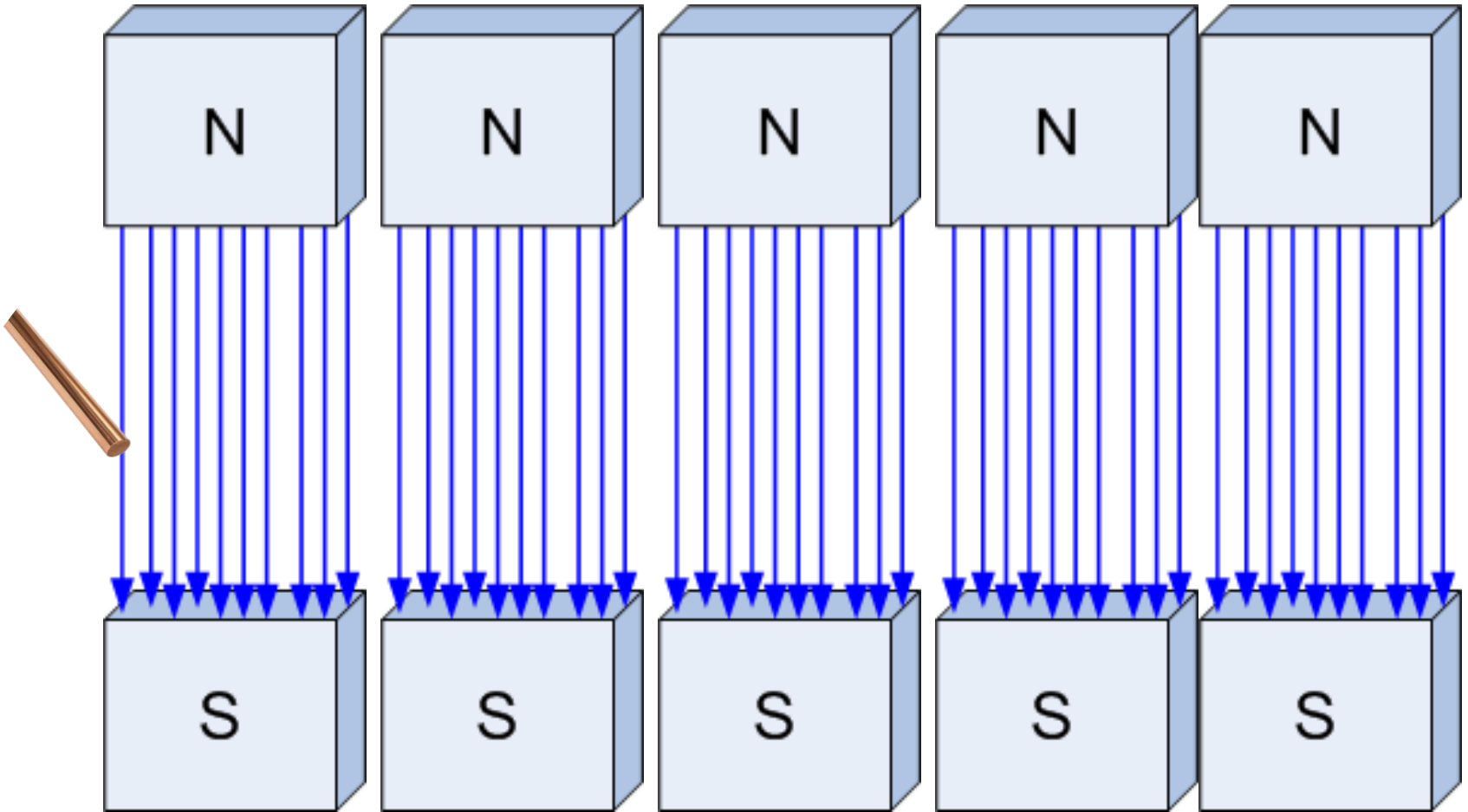
Dynamically induced EMF

- When the magnetic field is stationery and constant
- But the conductor physically moves in the magnetic field
- Then EMF induced in the conductor due to change in flux linkage is called ***dynamically induced EMF***



DC Generator - Linear

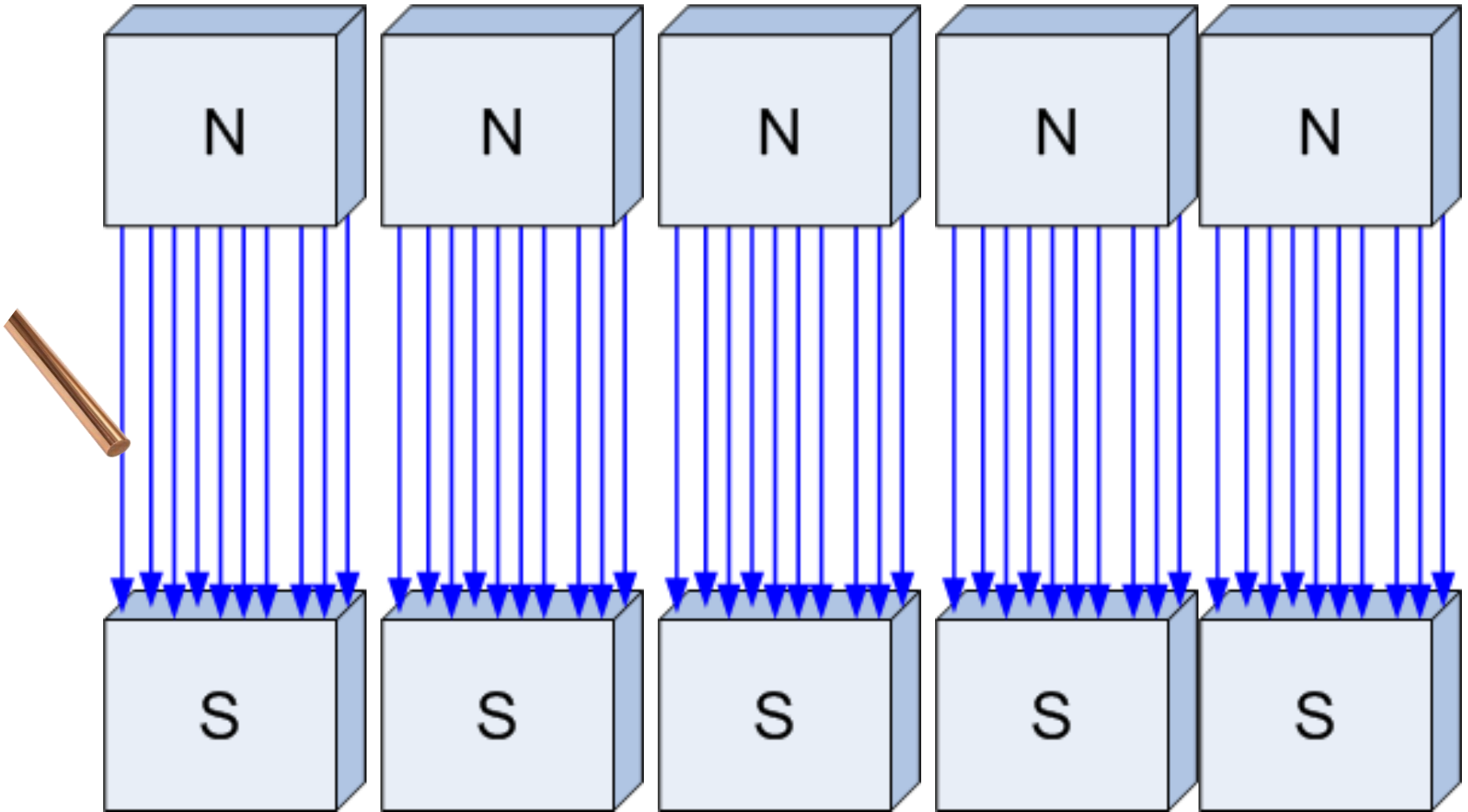
- Mechanical force is given on the conductor to move it
- Electricity available across two ends of the conductor
- But, for continuous electricity, the system should be very long



DC Generator - Linear

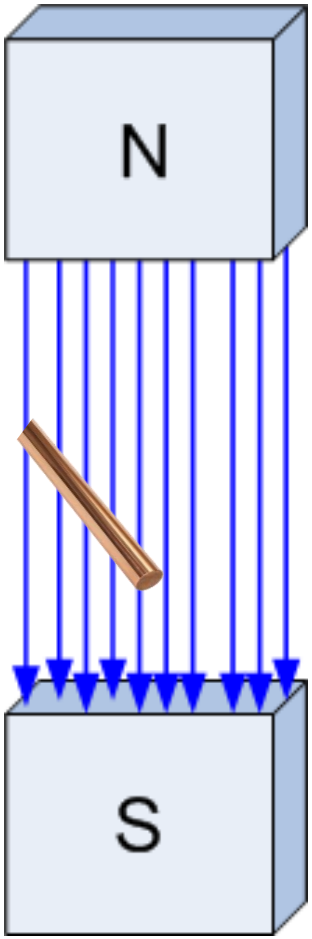
- Also the conductor needs to be brought back to starting positi
  to start generating electricity again
- **Make the whole structure circular**

Solution?



DC Generator - Circular

- Keep the magnet stationary (outside)
- **Rotate the conductor in the magnetic field**

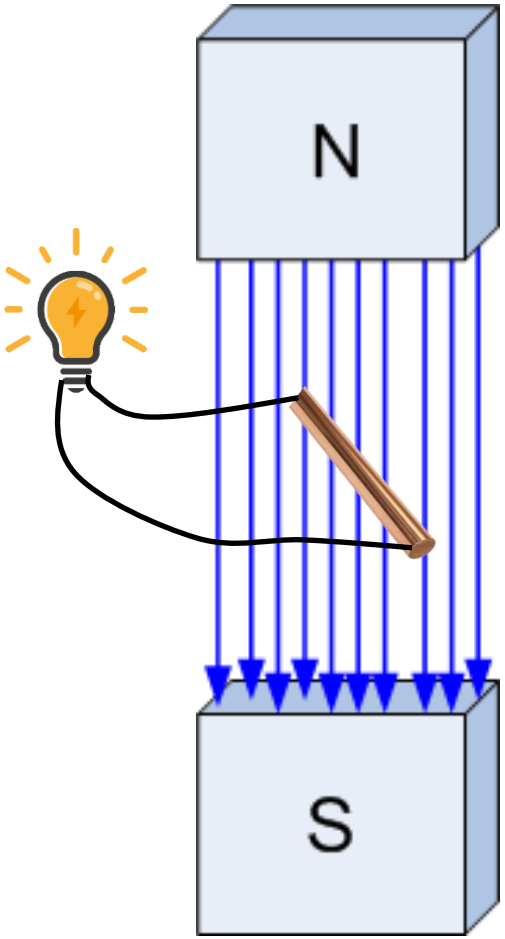


- This saves lots of linear space
- **Electricity continues as long as the conductor is rotated**
- Conductor automatically comes back to initial position after one rotation
- **But: There is a problem**

DC Generator - Circular

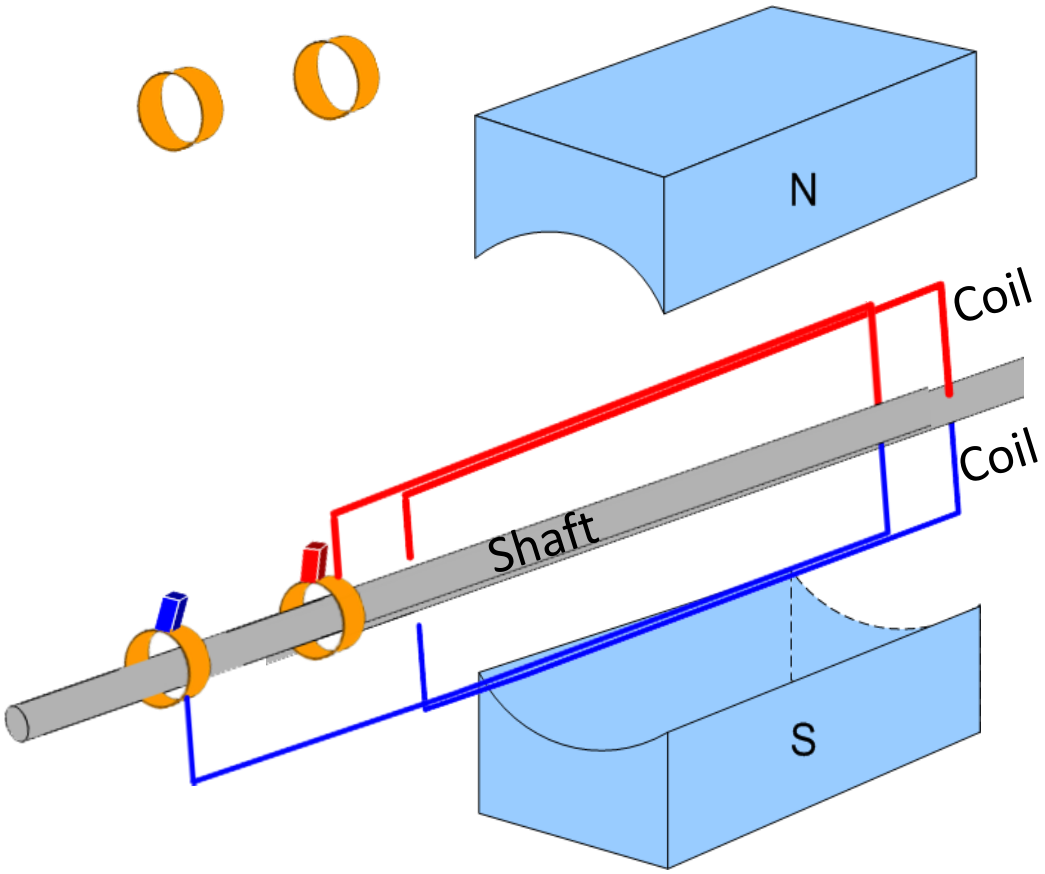
- The electrical load (e.g. bulb) also has to rotate along with the conductor

Problem?



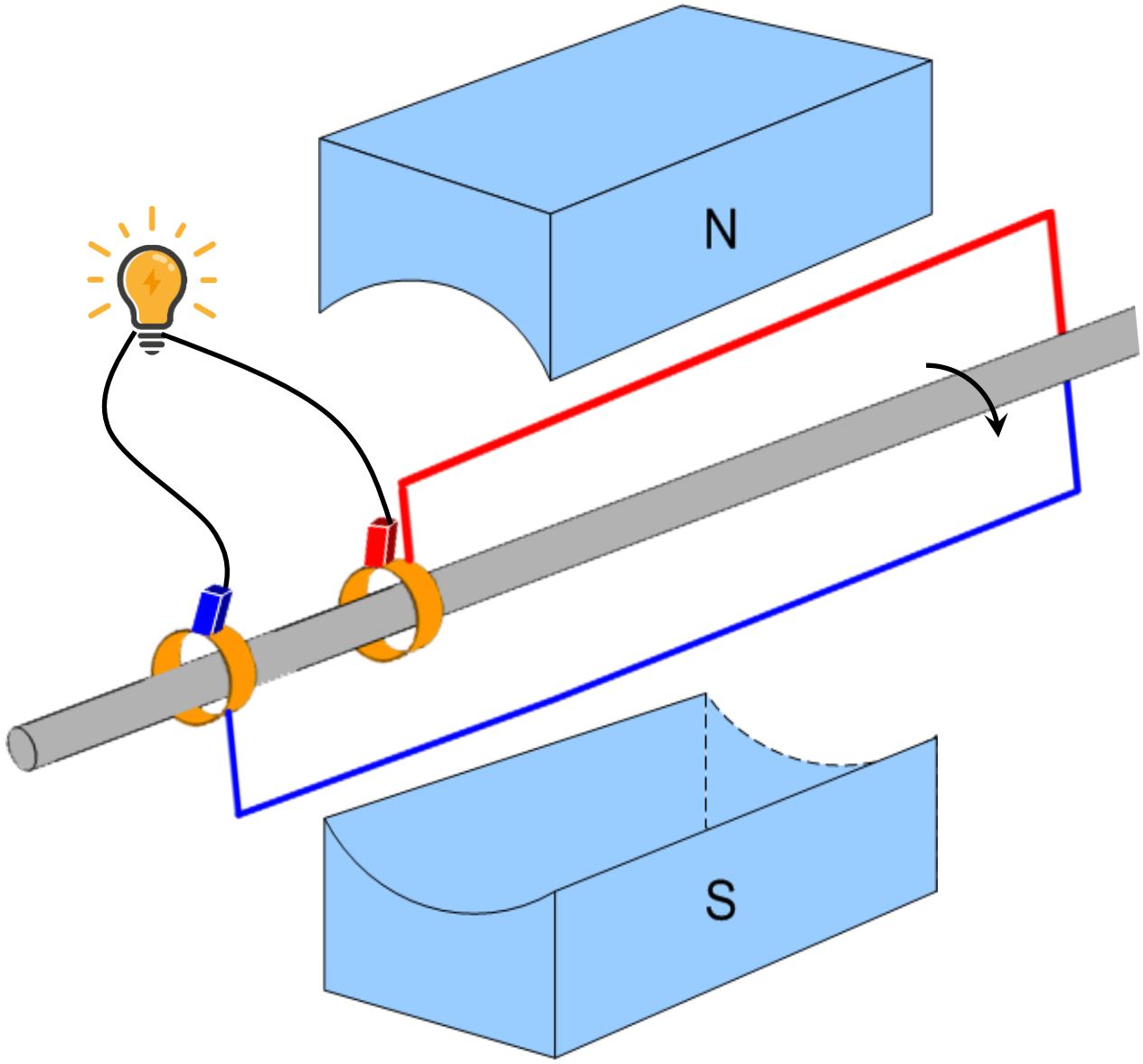
Solution?

Elementary DC Generator



- Pair of semi-circular shaped magnets (field system or the poles)
- The coil is mounted on shaft (armature)
- Two metal rings (slip ring) connected permanently to the two ends of the coil
- Two conducting brushes touch the rings

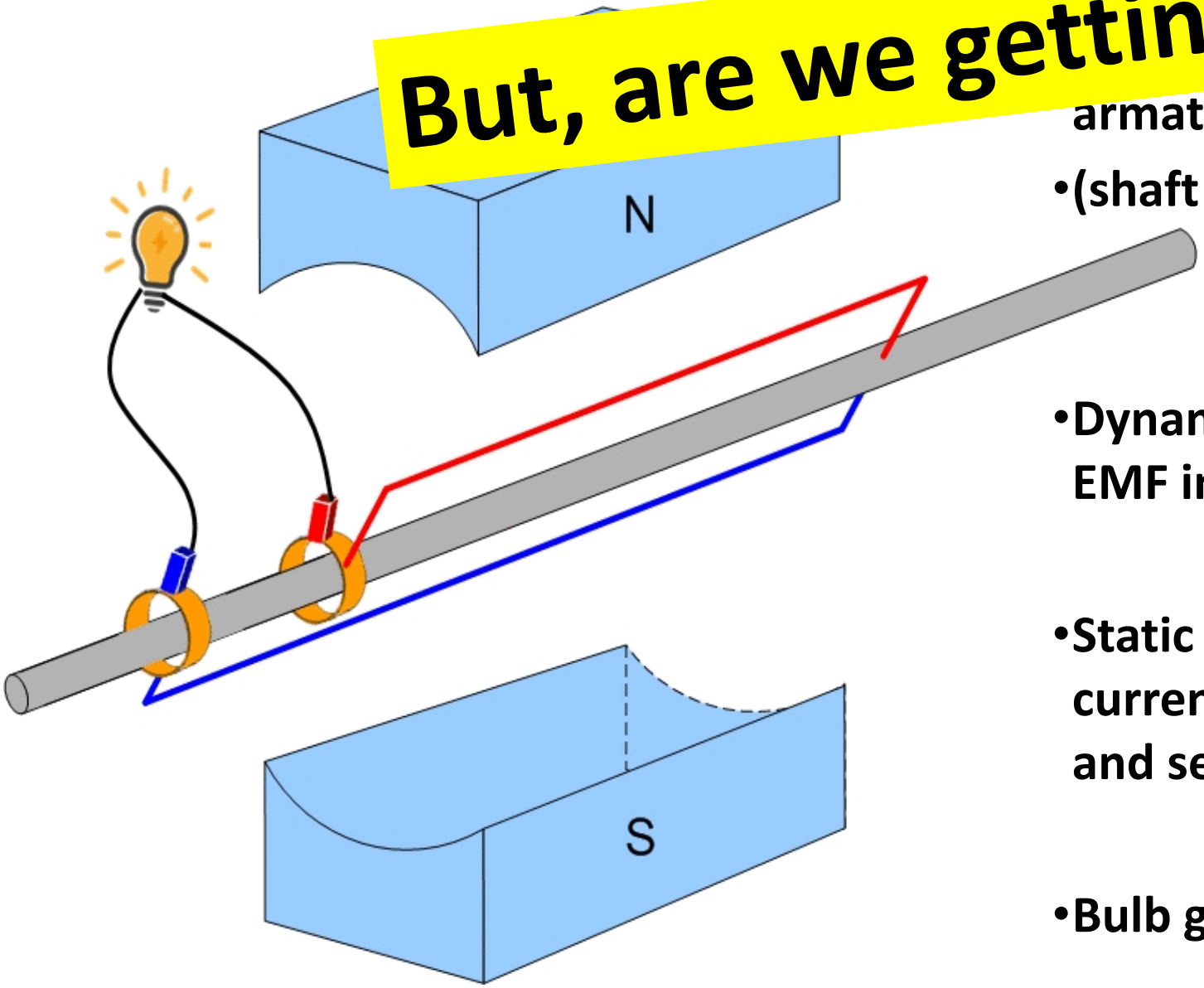
Elementary DC Generator



- External electrical load connected to the two brushes
- The two rings also rotate as shaft and coil rotate
- But brushes are static
- Brushes touch the slip ring surface and collect current from the rotating rings

Elementary DC Generator

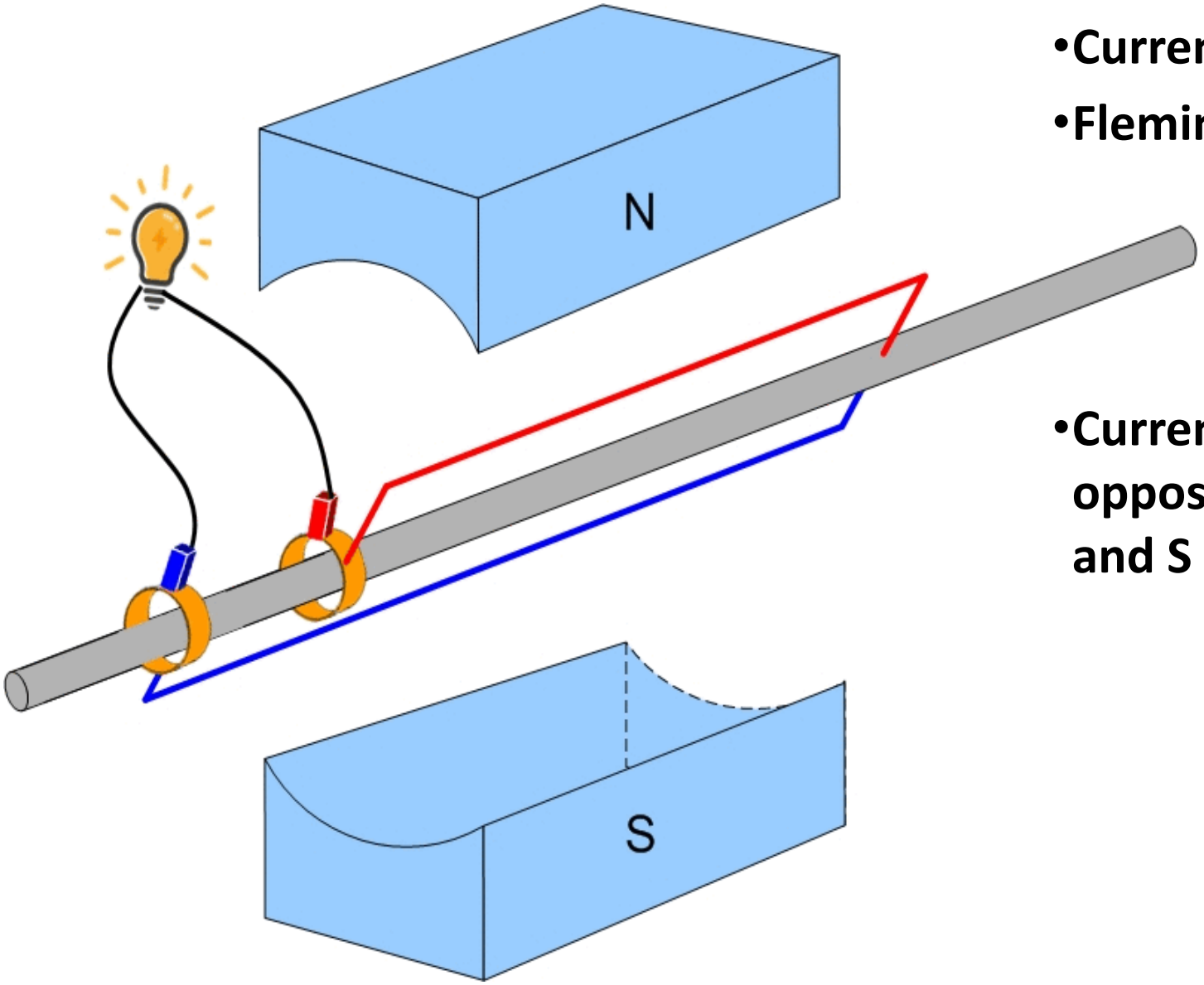
But, are we getting DC?



armature

- (shaft + coil+ rings)
- Dynamically induced EMF in coil
- Static brushes collect current from rings and send to bulb
- Bulb glows

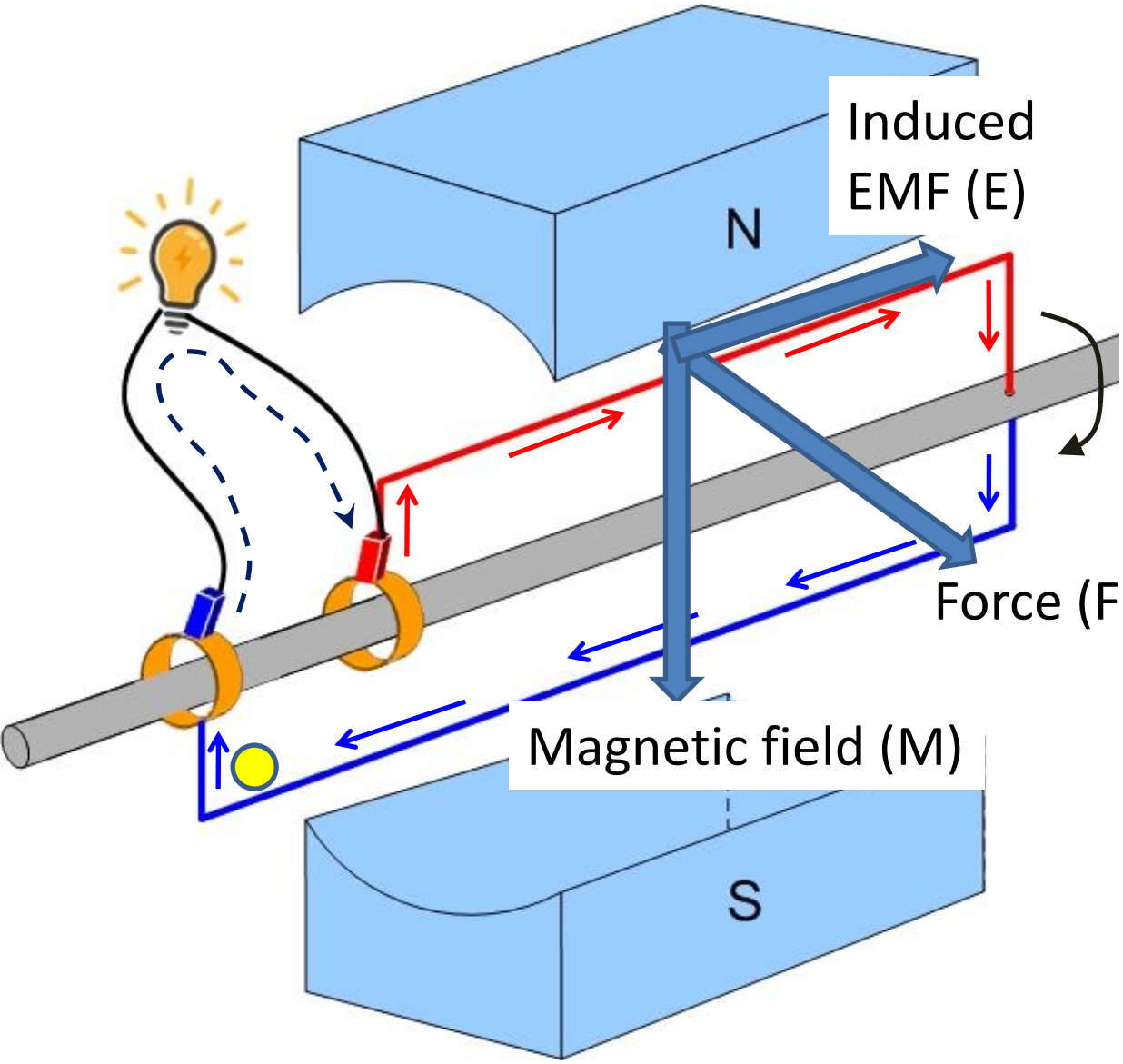
Elementary DC Generator



- **Current direction**
- **Fleming's RH rule**

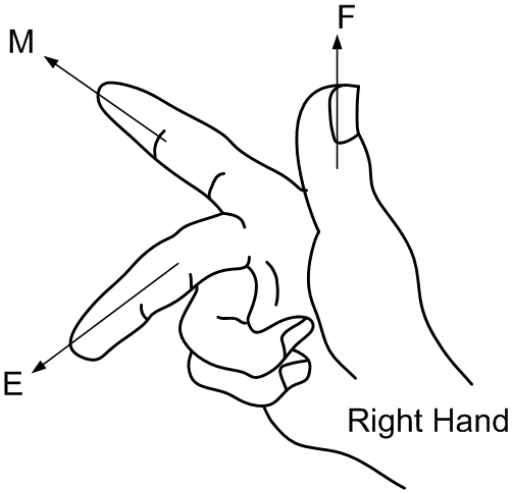
- **Current direction is opposite under N pole and S pole**

Elementary DC Generator



Position 1 (0^0)

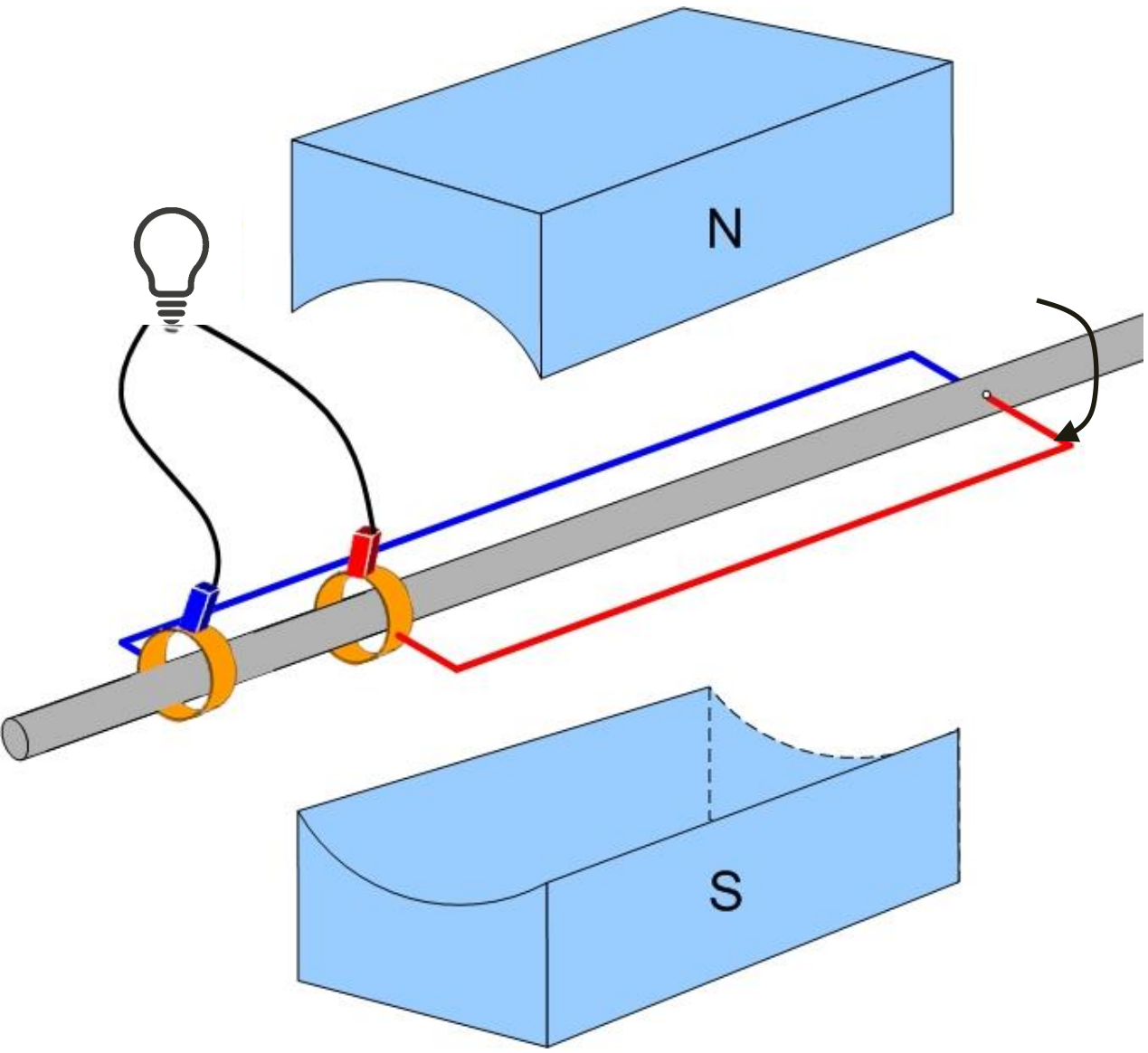
Red conductor under N



Blue under S

Current flows from Left to Right in bulb

Elementary DC Generator



Position 2 (90^0)

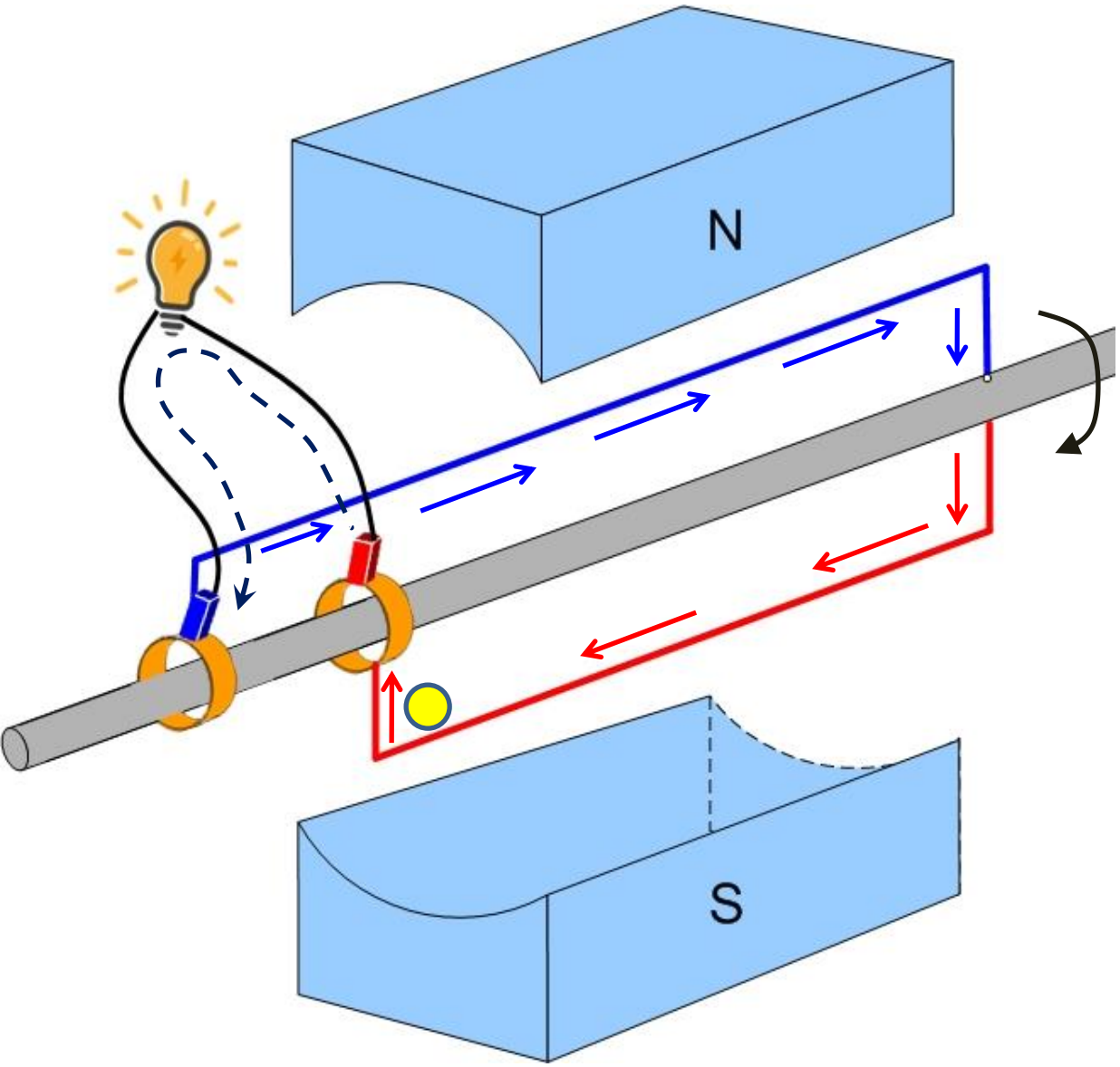
Coil midway between N and S

Magnetic neutral plane

So, no EMF induced

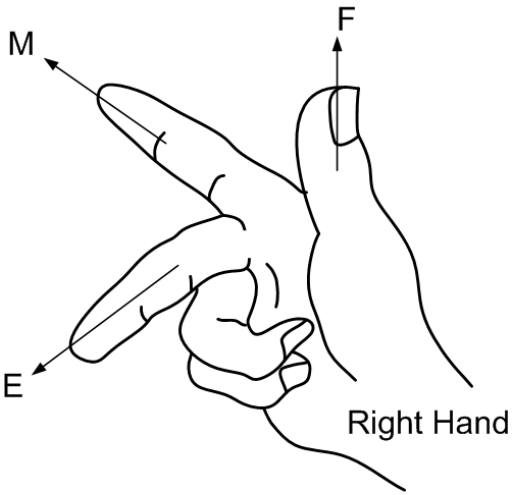
So, no current in bulb

Elementary DC Generator



Position 3 (180^0)

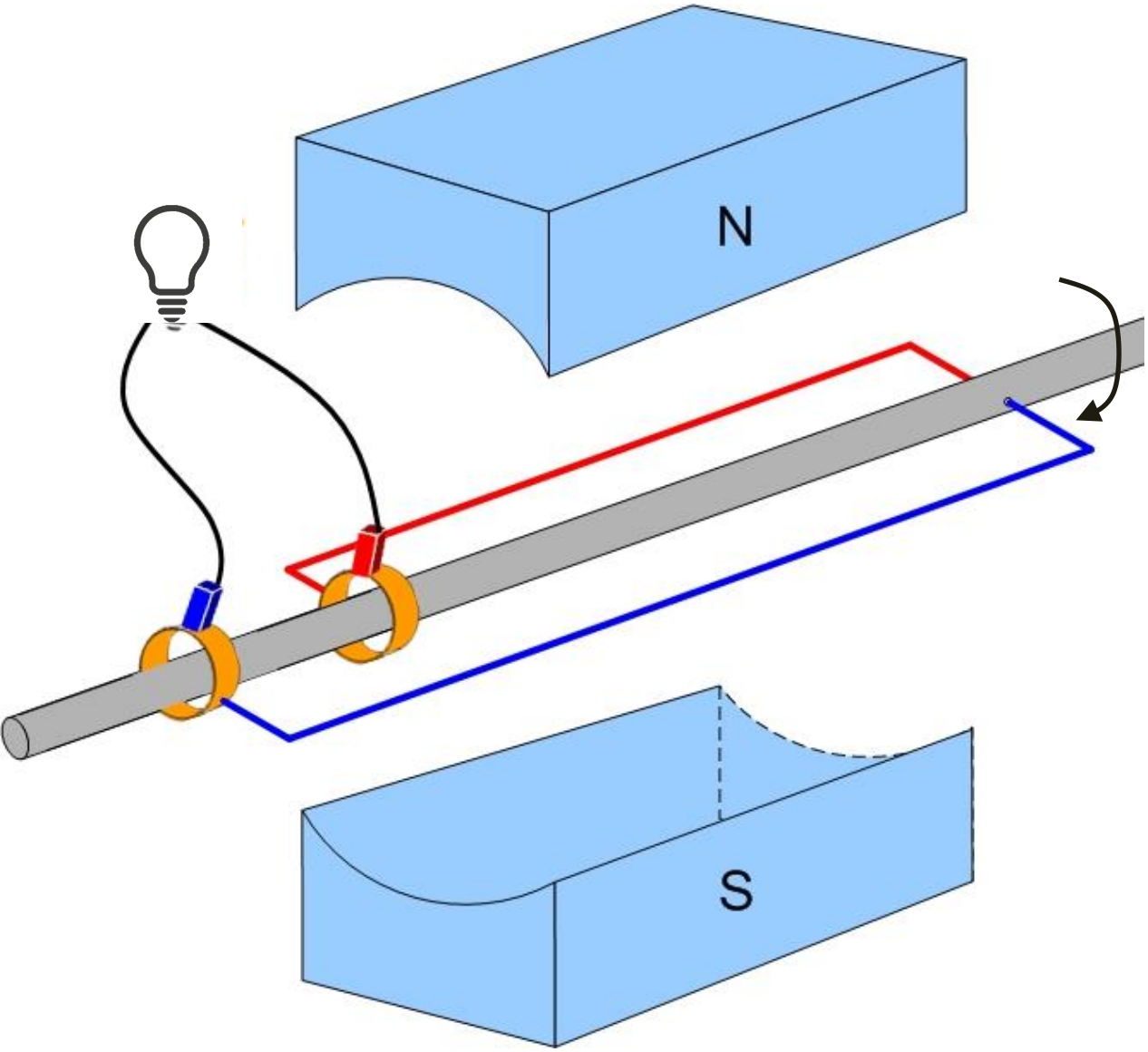
Red conductor under S



Blue under N

Current flows from Right to Left in bulb

Elementary DC Generator



Position 4 (270^0)

Coil midway between N and S

Magnetic neutral plane

So, no EMF induced

So no current in bulb

Elementary DC Generator

Position 5 (360^0)

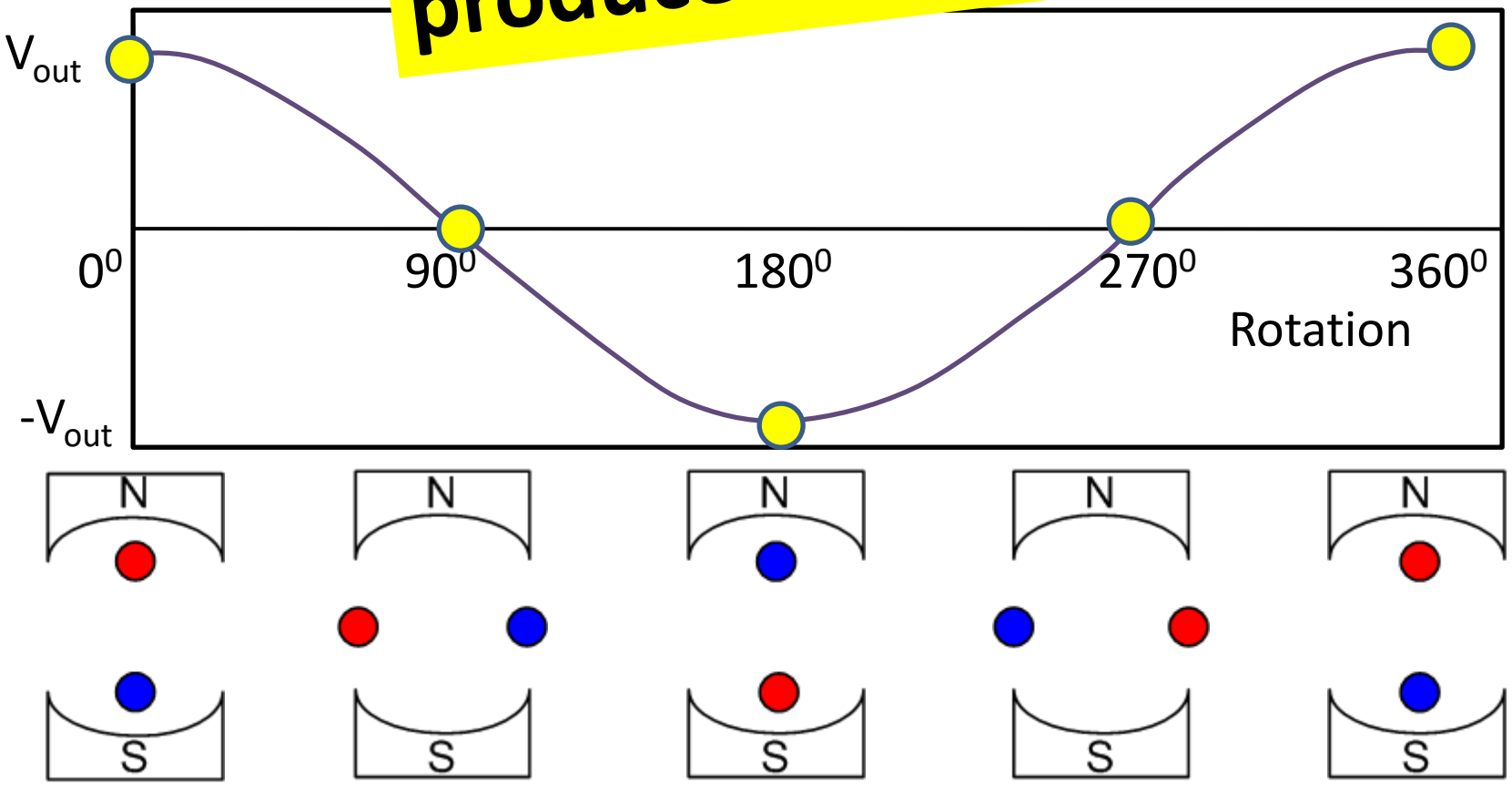
Same as position 1 (0^0)

Current flows from Left to Right in bulb

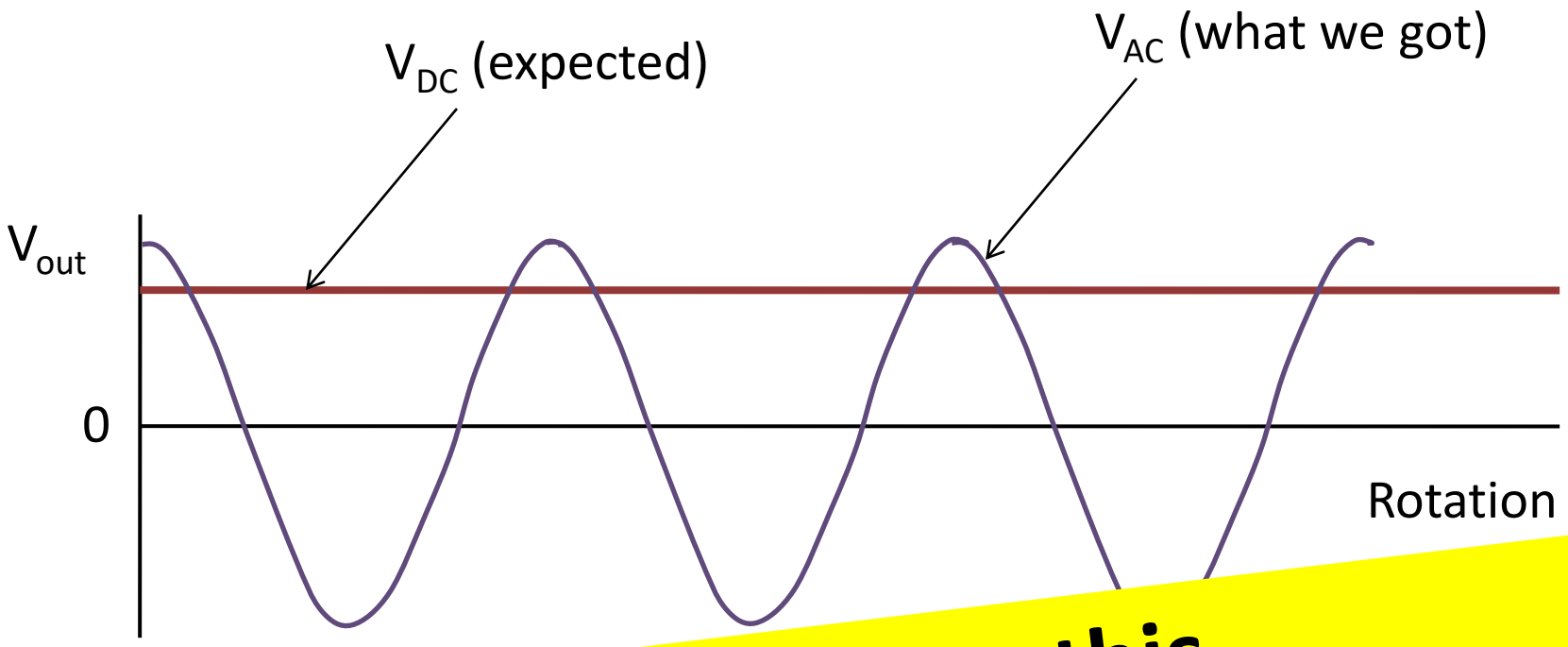
Elementary DC Generator

- The generated EMF is th
  - It varies in
  - It varies in d

Continuous rotation will thus produce AC signal at output

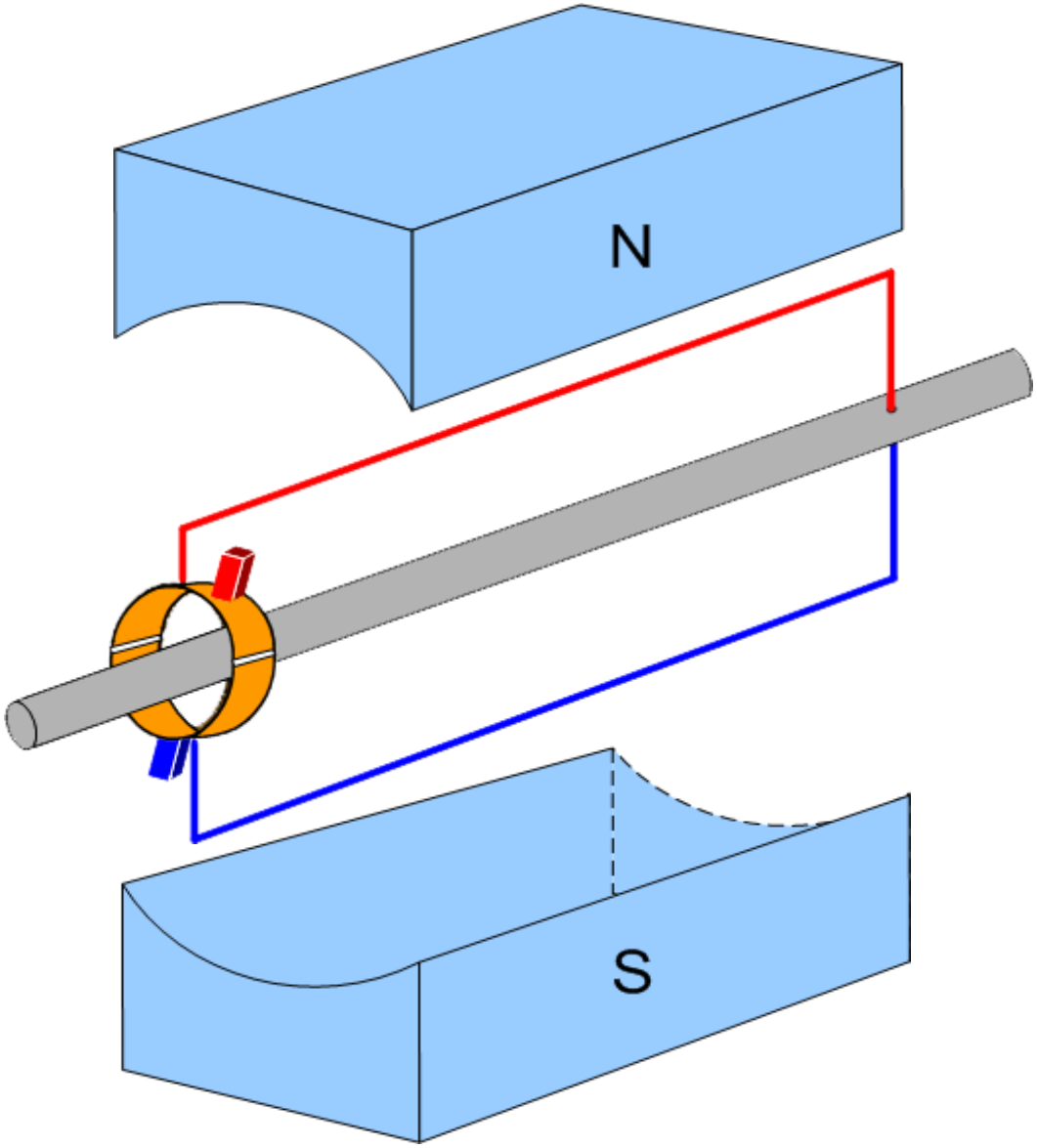


Elementary DC Generator



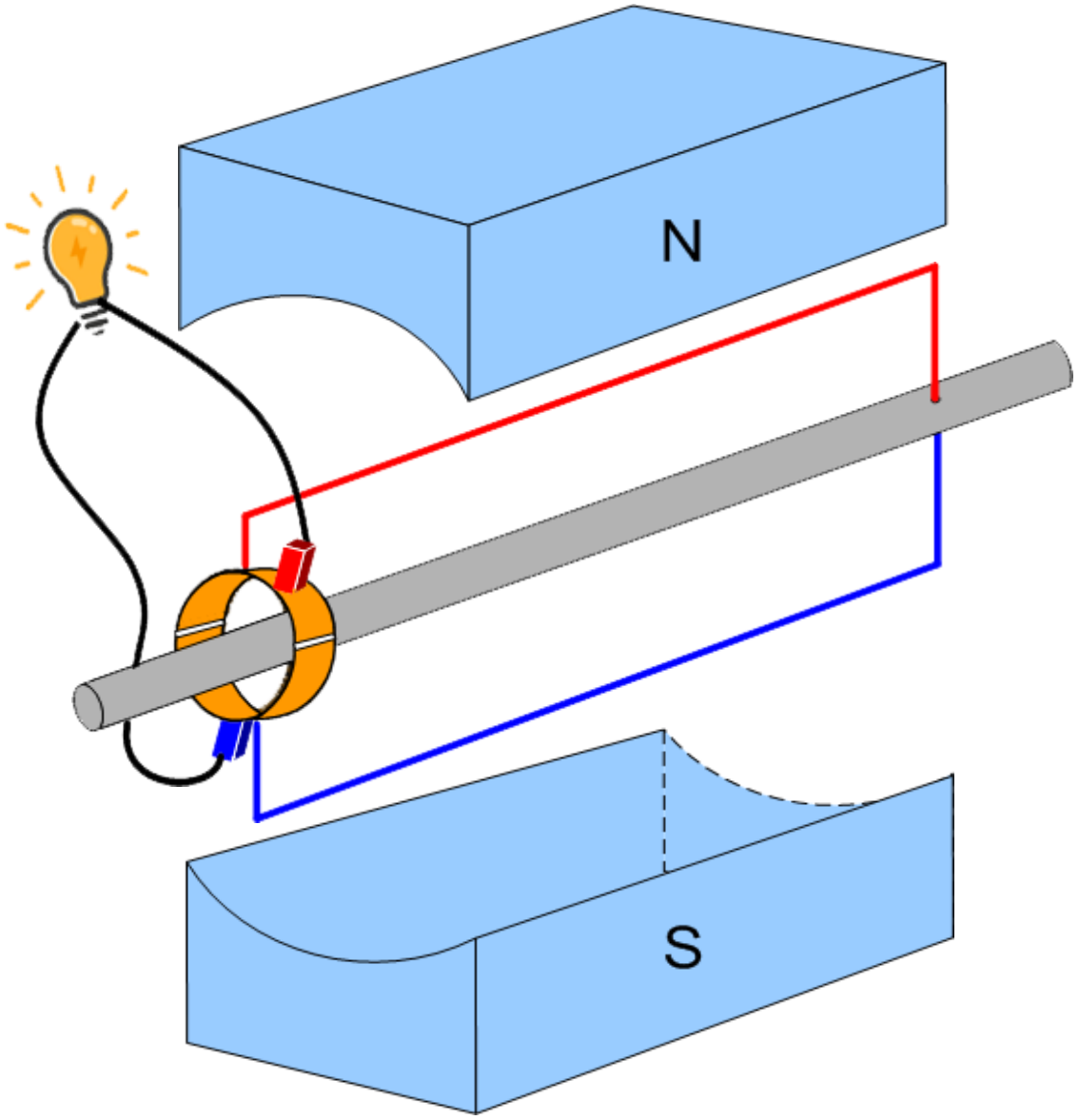
How can we convert this internally generated AC signal to DC to be supplied to the output?

Rectification of Alternating EMF



- Use only one ring in place of two rings
- Split the ring in two halves insulated from each other
- To each half of the ring, one coil side is permanently connected
- The two brushes touch the two halves of the ring

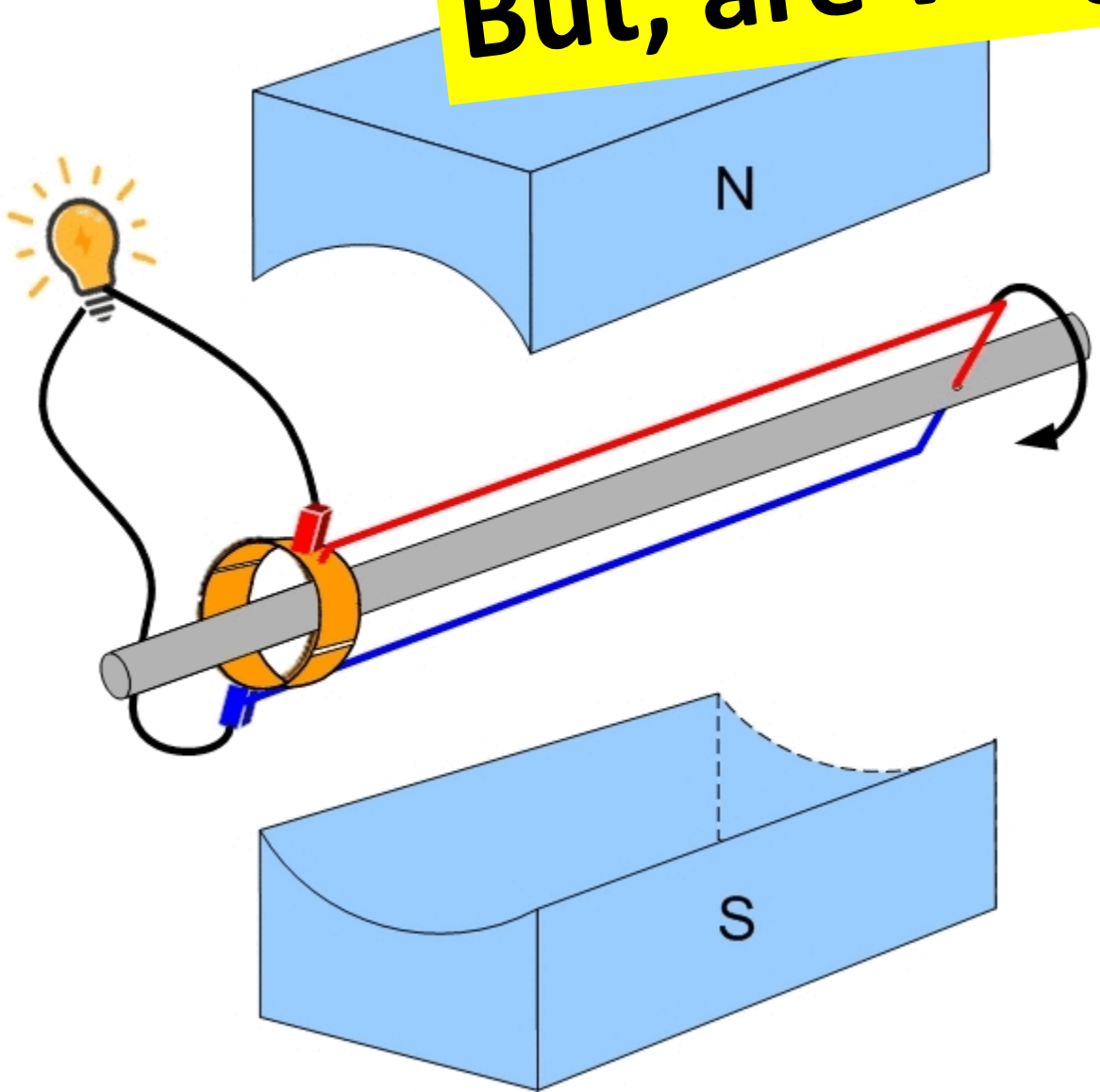
Rectification of Alternating EMF



- External electrical load connected to the two brushes
- The split ring also rotates along with the shaft and coil
- But brushes are static

Rectification of Alternating EMF

But, are we getting DC?



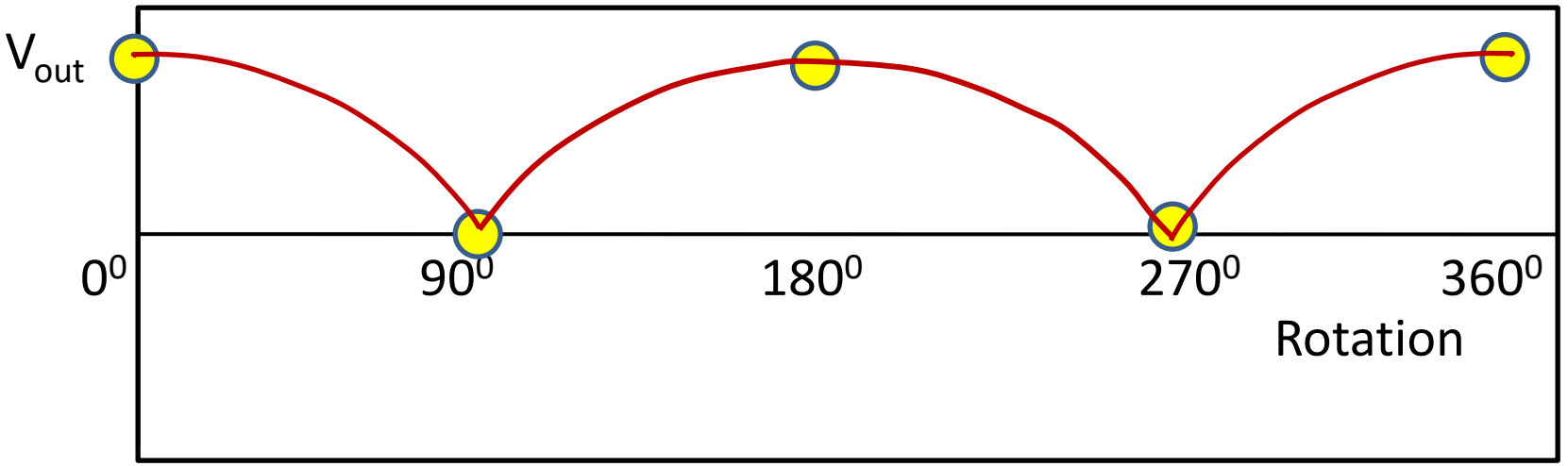
armature

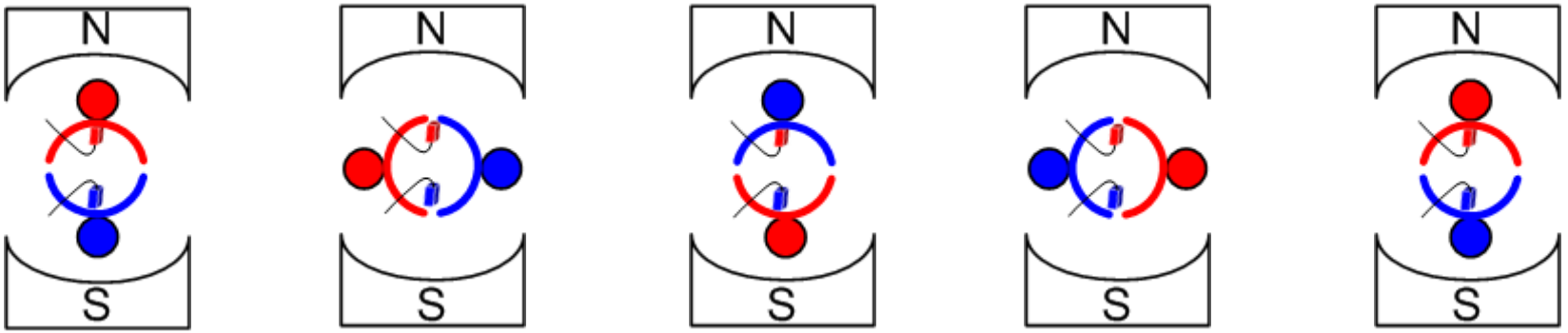
- (shaft + coil+ ring)
- Dynamically induced EMF in coil
- Static brushes collect current from rings and send to bulb

Rectification of Al… MF

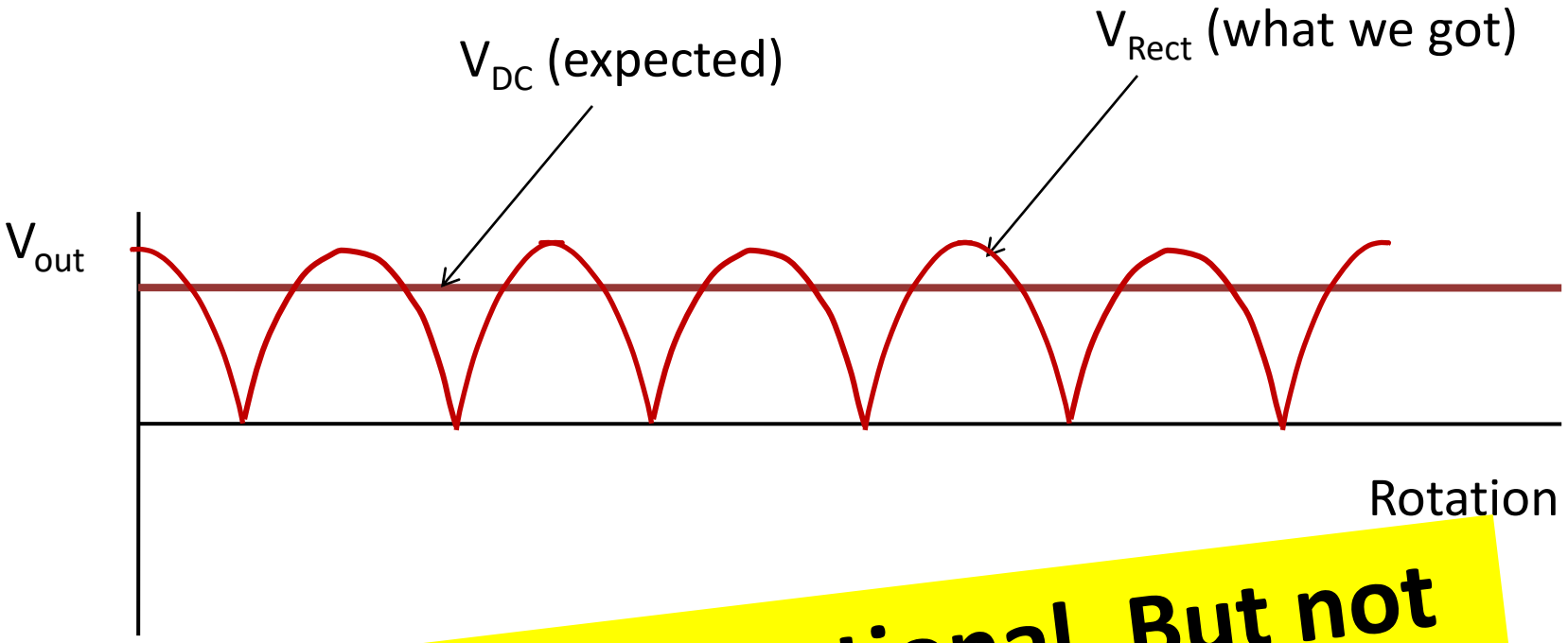
Use of split-rings produce rectified AC signal at output

- The
  - I
  - **B… remains unidirectional** (does not go negative)





Rectification of Alternating EMF



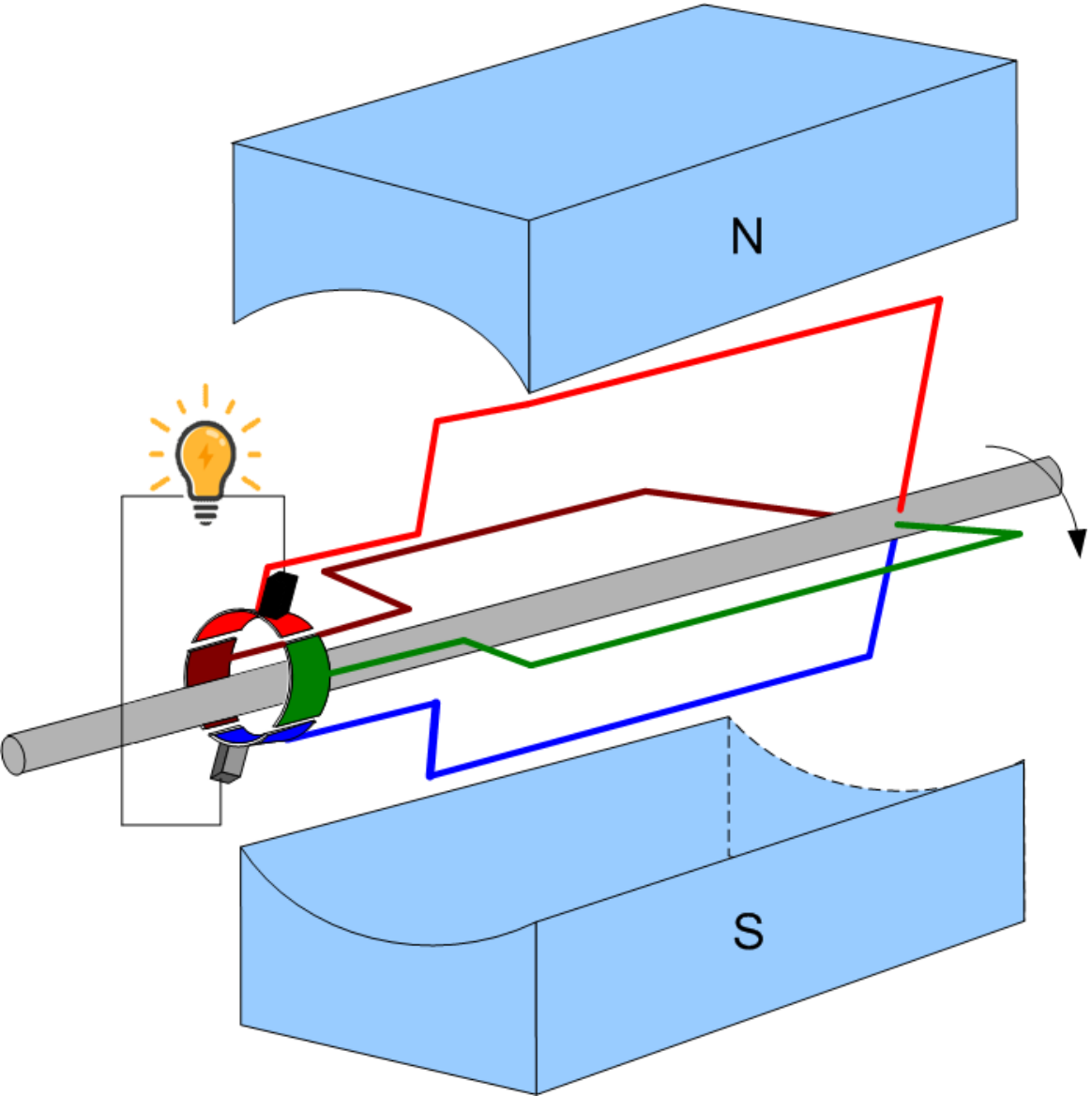
The EMF is unidirectional. But not pure DC. How can we reduce the ripples?

Ripples in DC generator output

- Ripples in the DC generator output voltage can be reduced by:
  - Using more number of coils
  - Using more number of splits in the split ring
  - Each coil side will be connected to each split section of the ring
  - This never allows the voltage to drop to zero
  - This increases the average value of DC output voltage
  - This reduces ripples in output
  - The output voltage thus approaches more towards pure DC

Ripples in DC generator output

For example, two coils (4 coil sides) with 4 split sections in the ring is shown:

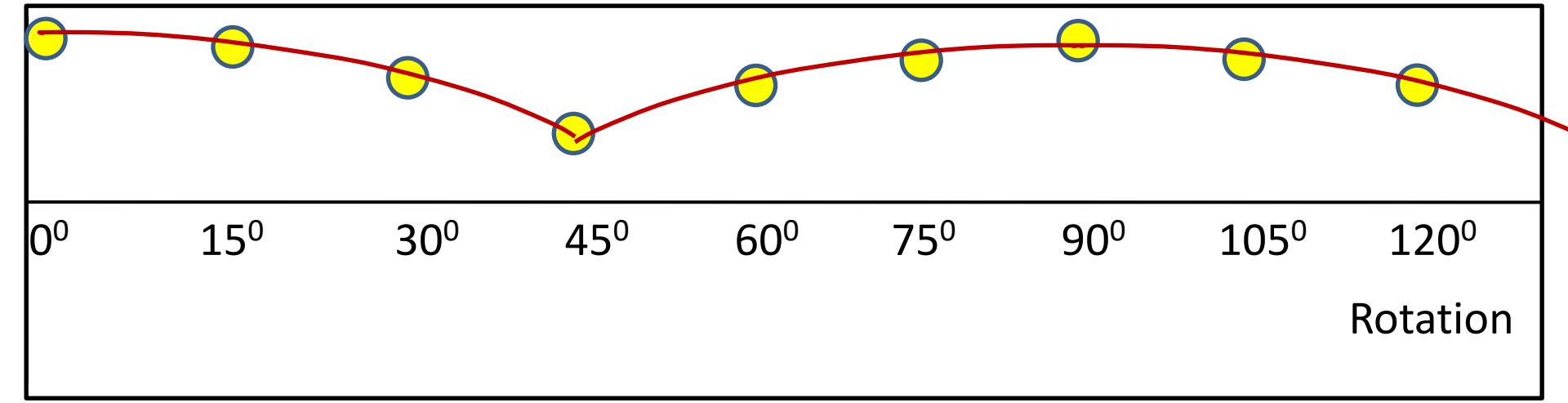


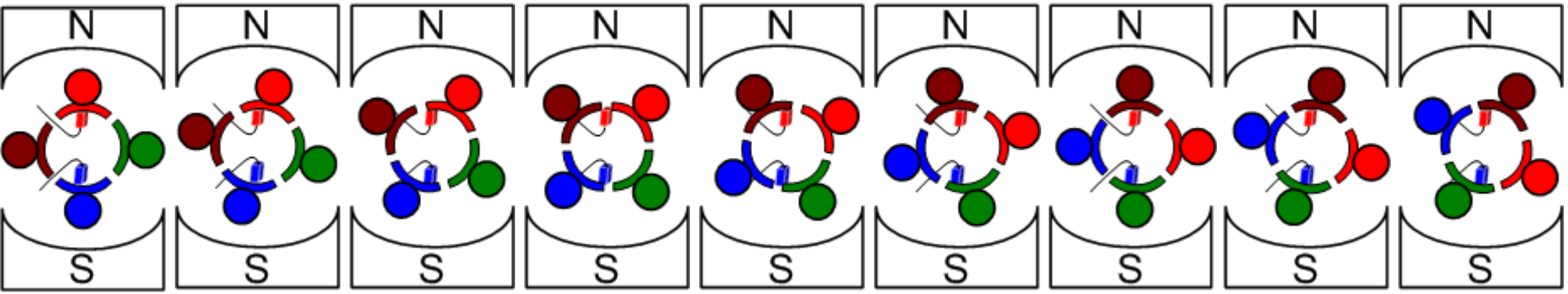
- Whichever coil has its sides directly under the poles, will have maximum EMF
- When one coil is at magnetic neutral position, the other coil is at maximum voltage position

Ripples in DC generator output

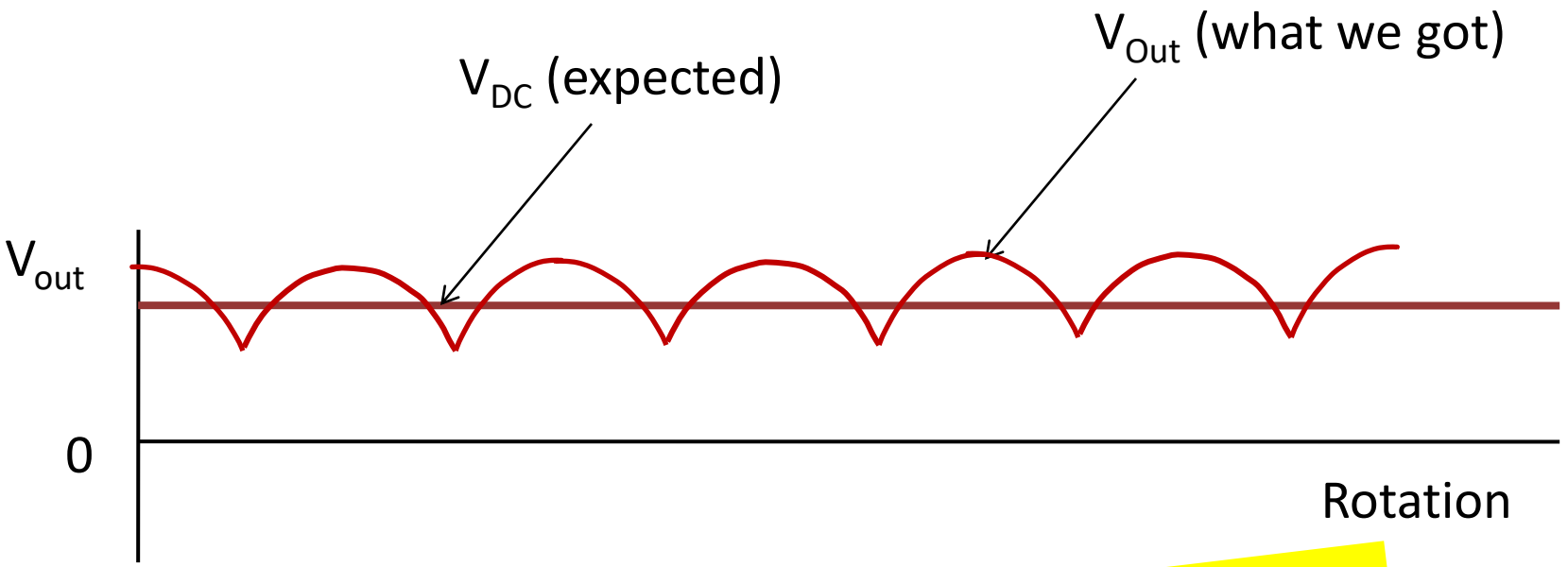
- The generated EMF is still not
  - It remains unidirectional
  - Never comes down to zero, so ripples less, average value more

Situation improved





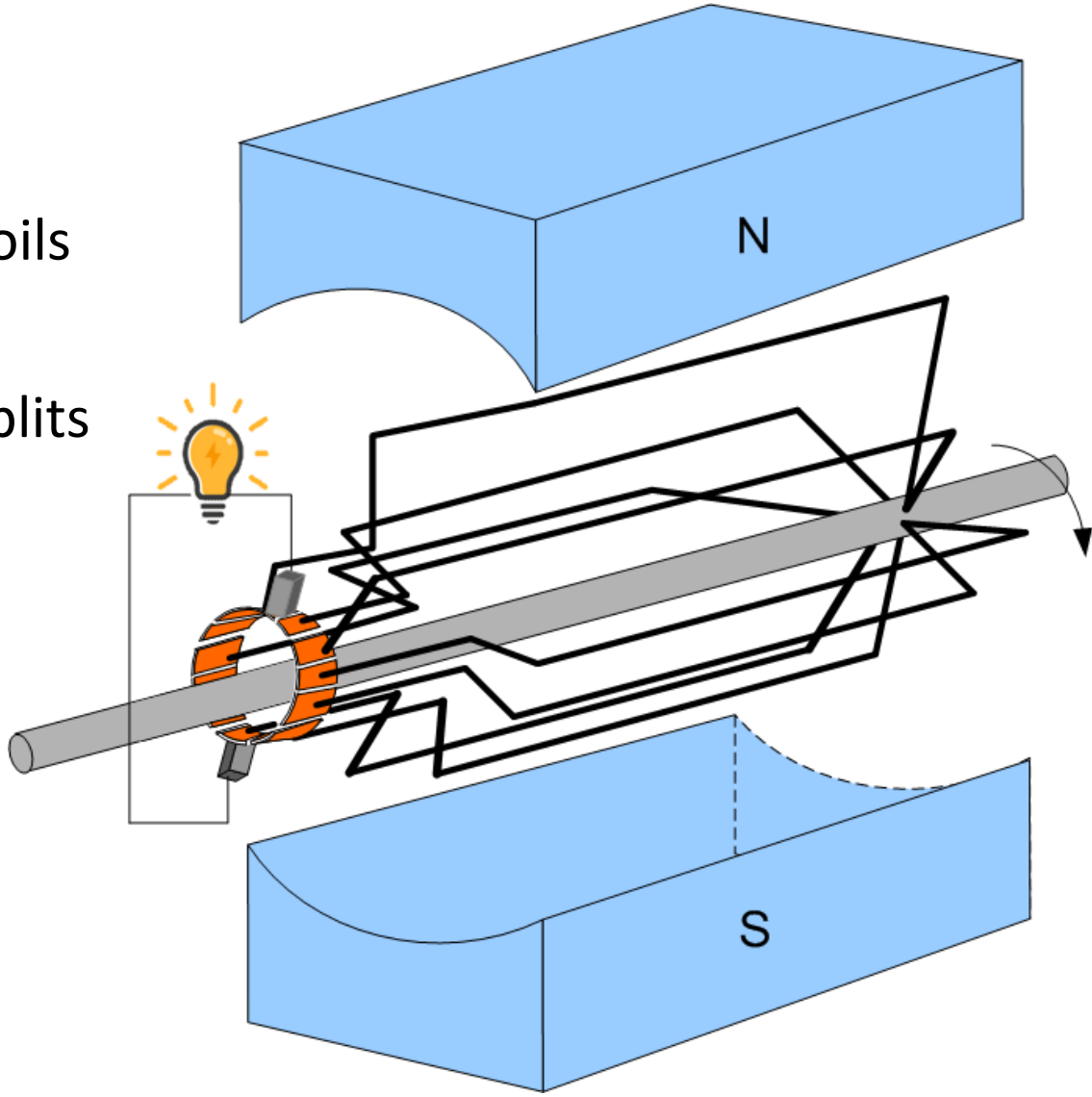
Ripples in DC generator output



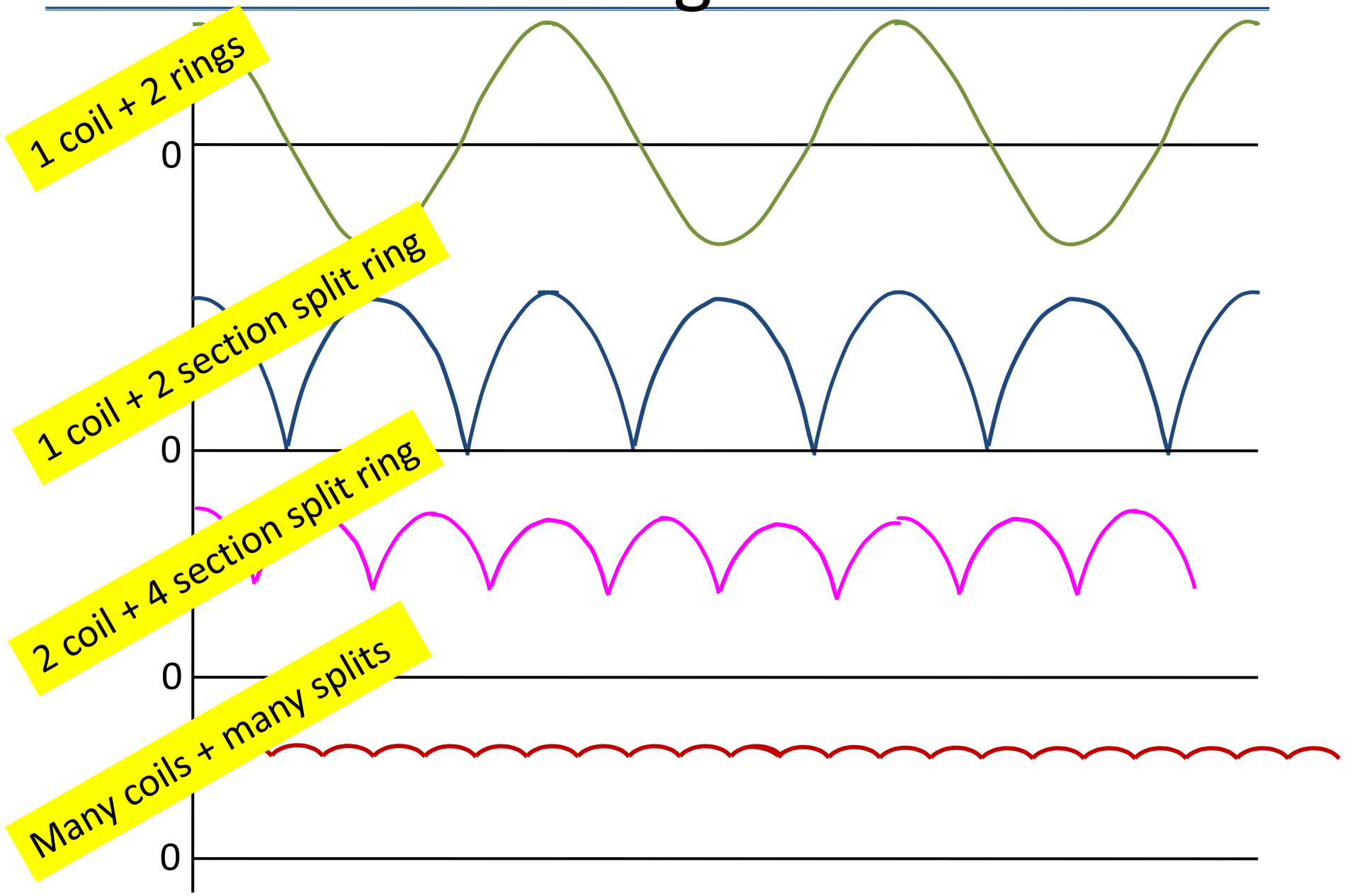
- **Average value much increased**
- **Ripple content reduced**
- **How to reduce ripple further?**

EMF in DC generator

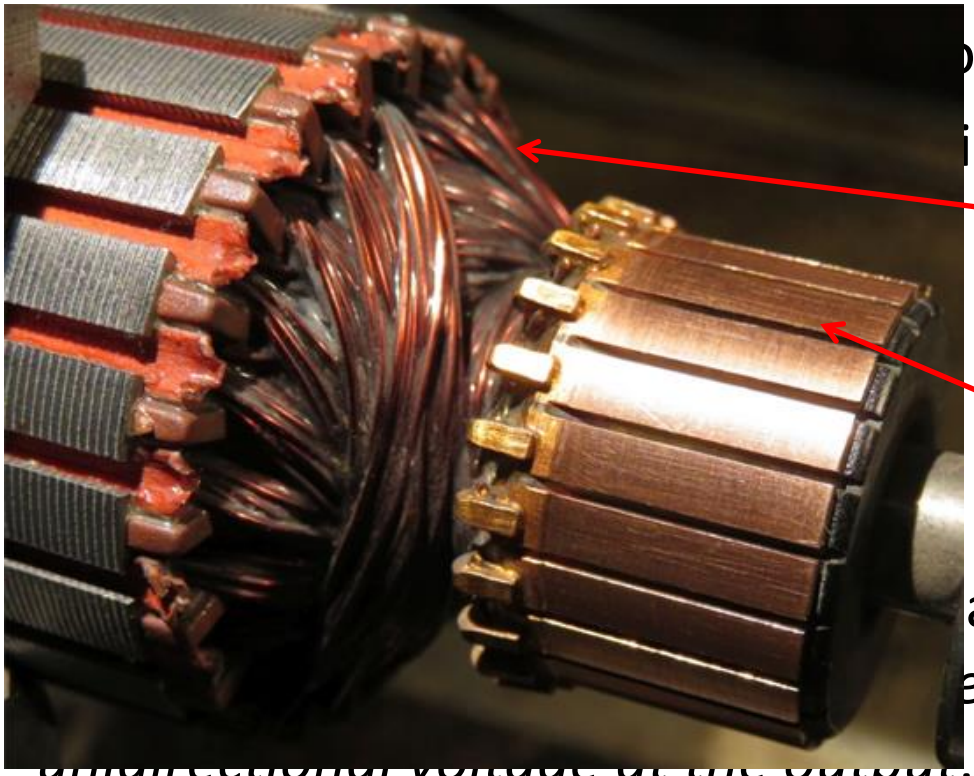
- Ripples can **thus** further be reduced by
  - Increasing number of coils
  - Increasing number of splits in the ring



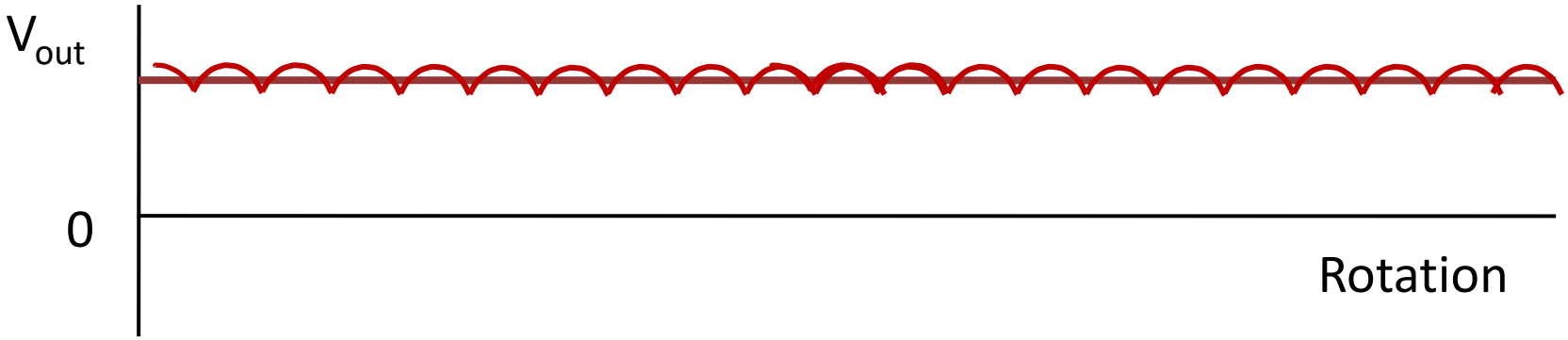
EMF in DC generator



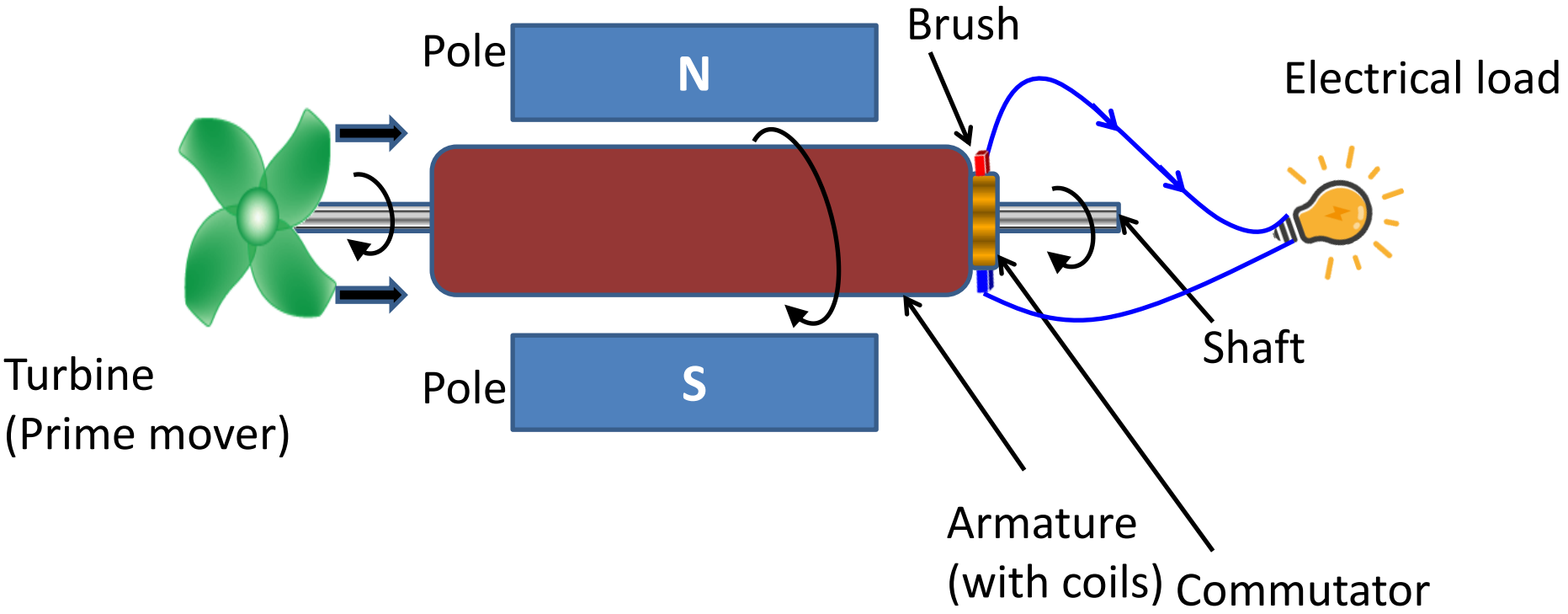
EMF in DC generator



- ore than 20 such coils
- in the ring
- as the '**commutator**', that
- *ernating EMF into a unidirectional voltage at the output.*



Basic DC Generator



- Static parts
  - Poles
  - Brushes
  - Electrical load
- Rotating parts
  - Armature (coils)
  - Commutator
  - Shaft
  - Turbine

DC Motor

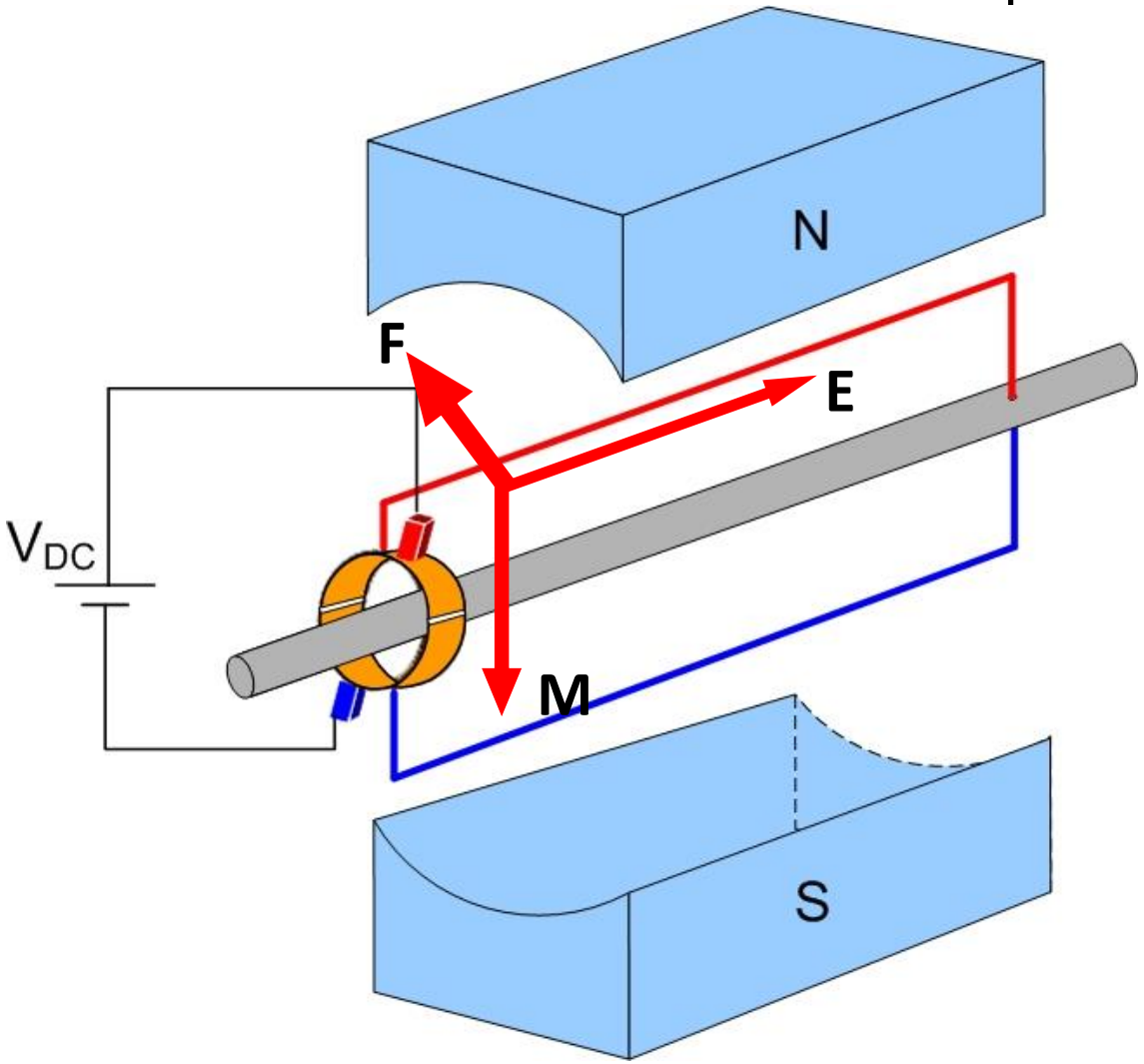
- **The same machine can be used as motor**
- **Give electricity input to armature**
- **Electricity from supply passes through brush and commutator and then to the armature coils**
- **Lorentz force between the current carrying coils and magnetic field of the poles**
- **That makes the armature + shaft to rotate**

- Brushes
- Electricity supply

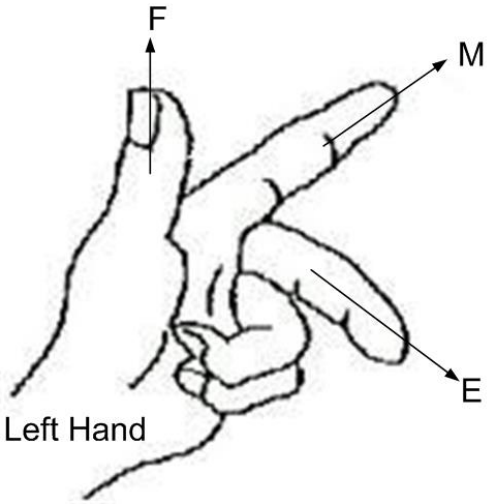
- Commutator
- Shaft
- Fan

DC Motor – basic operation

- The same machine with 1 coil + 2 split-rings can be used

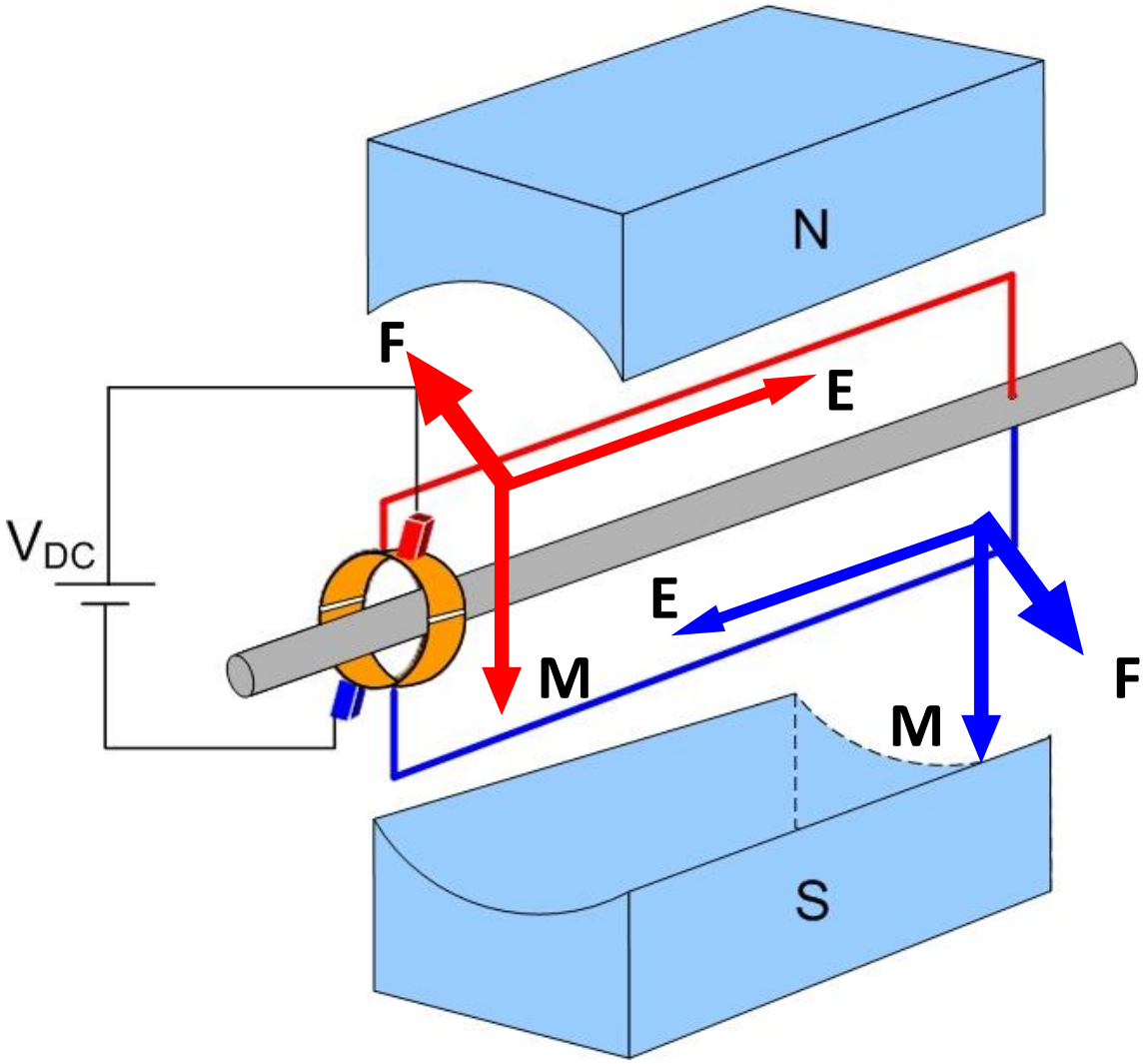


- FLR

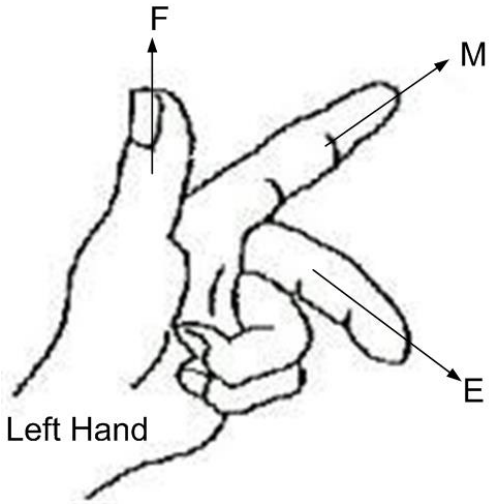


- **RED coil side**
- Current direction
- Magnetic field direction
- Force direction

DC Motor – basic operation



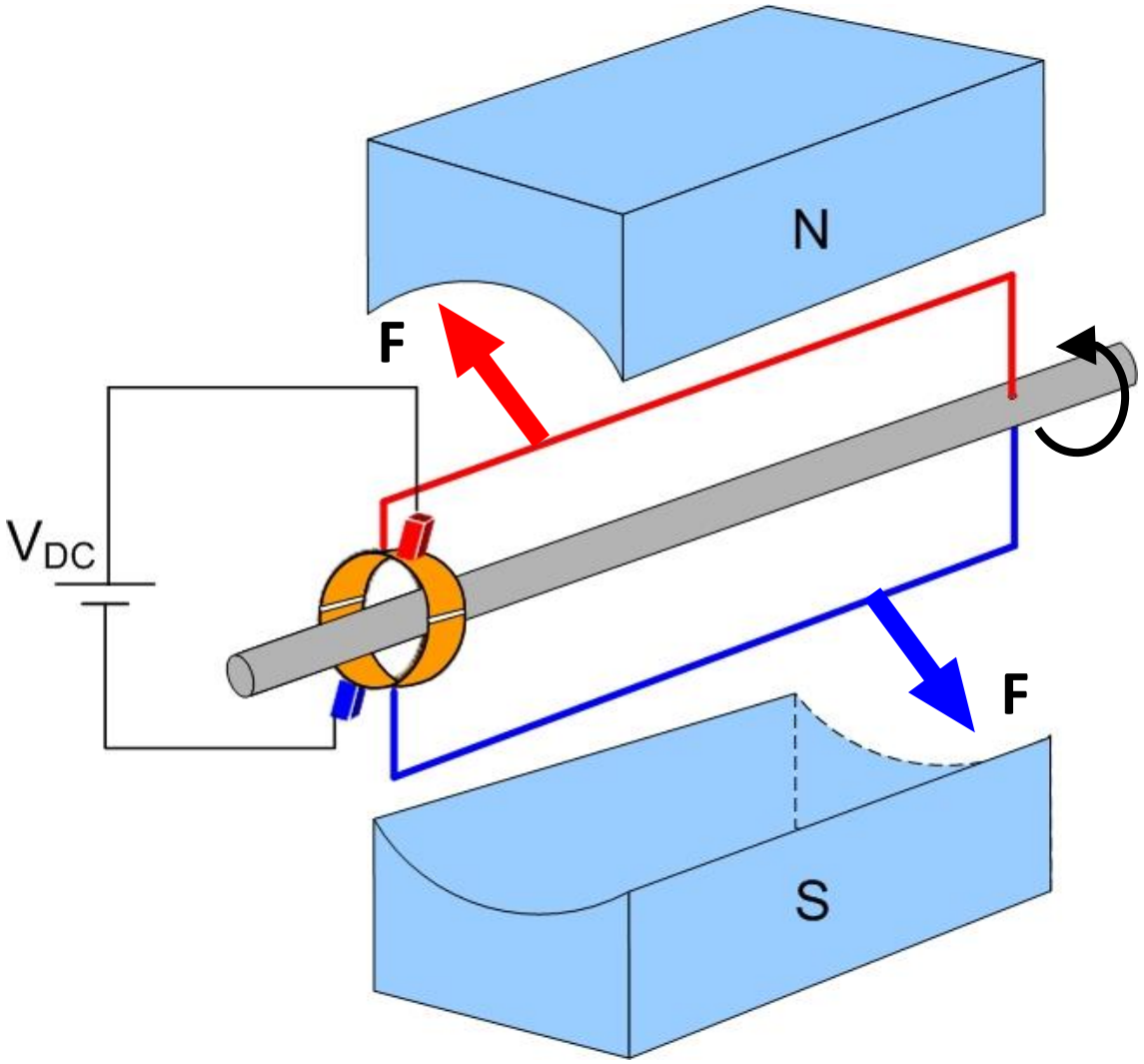
- FLR



- **Blue coil side**
- Current direction
- Magnetic field direction
- Force direction

DC Motor – basic operation

- **Force on Red and Blue coil sides are opposite**



- **This produces a rotating torque**
- But, torque is not constant
- Depends on coil position w.r.t. poles
- Thus torque ripples
- Torque ripples reduced by using large number of coils and large number of splits in the ring (commutator)

Summary

- DC generators and motors are both electromechanical devices
- Generators convert mechanical energy to electrical energy
- Motors convert electrical energy to mechanical energy
- DC generators guided by Fleming's RH rule
- DC motors guided by Fleming's LH rule
- Magnets are fixed
- Coils rotate in the space between magnets
- Commutator (metal ring with large number of splits) used to reduce voltage ripples in generator and torque ripples in motor
- Brushes are used to carry current between static external circuit and rotating armature through the commutator