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# Force Between Conductors KSCIFBCD

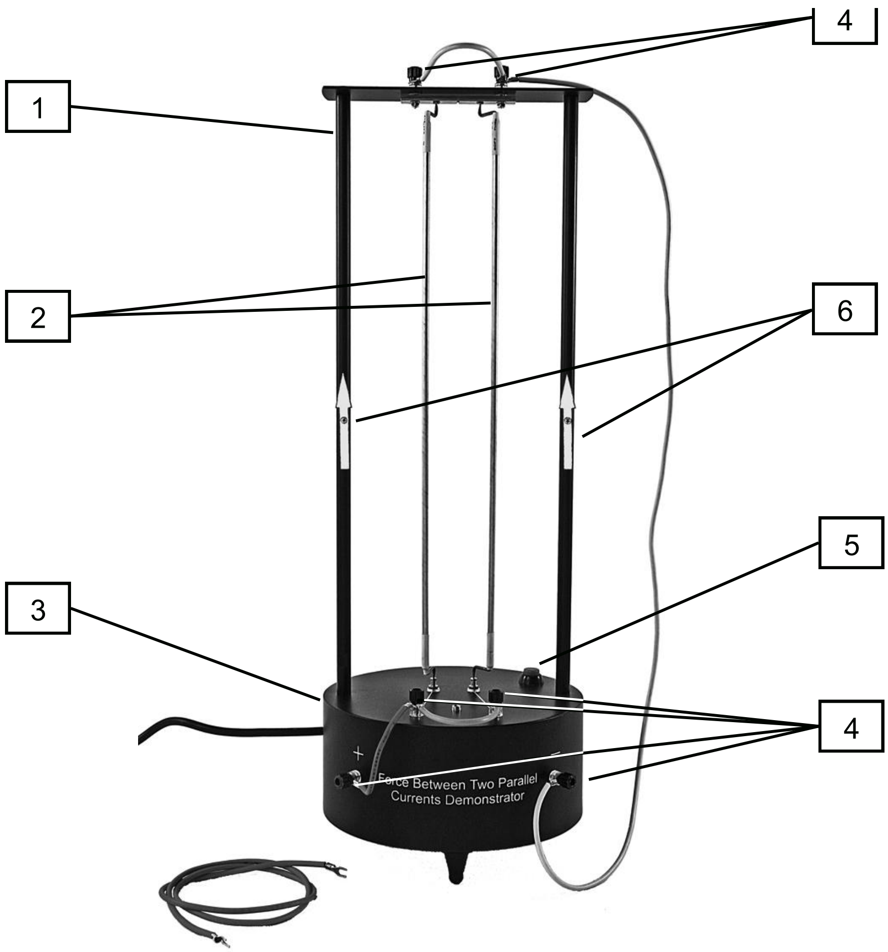


*Figure 1*

## DESCRIPTION

A basic property of electromagnetism is the mechanical force which exists between two neighboring, current-carrying conductors. This was first observed by Oersted in June of 1820 and was rapidly investigated by him as well as by Ampère, Biot and Savart, so that the theory was developed by the end of the same year. The unit of current, the Ampère, is defined in terms of this force. However, observing the small force with simple conductors requires large currents. The Force between Conductors Demonstrator offers a simple, direct method for accomplishing this usually difficult and often unsatisfying demonstration. The device consists of a metal frame (1, *Figure 1*), which supports two long straight conductors that can pivot about vertical axes (2). The base of the frame (3) contains a power supply to energize the conductors. Binding posts (4) allow voltage to be applied to the conductors in various configurations. A pushbutton (5) applies the voltage, allowing a large current to flow momentarily in the conductors. Two adjustable indicator arrows (6) show the direction of the current in each conductor. The movement of the conductors indicates the generation of a magnetic force between them.

## SPECIFICATIONS

| | | |
|---|---|---|
| Conductors: | Thin wall brass tubes with copper end pieces | |
| | | Length: 39.5 cm |
| | | Diameter: 4.4 mm |
| | | Lever arm: 2.5 cm |
| | | Cold resistance (each): Approx. 0.013Ω |
| Power: | Input: | 110VAC/60Hz, 345W (max., - operate for < 5 seconds) |
| | Output: | Open circuit voltage 4.0V d.c., operating voltage 0.5—1.5 V d.c. |
| | | Approx. operating currents: 55A in series, 2 x 37A in parallel |
| | | Fuse: Miniature fuse, 5 x 20 mm, 250V/3A |
| Dimensions: | Height 56.5 cm, base diameter 19 cm, base height 8.5 cm | |
| Weight: | 4.25 kg | |
| Connecting cords: | | 2 x 11 cm, 1 x 80 cm, spade lug connectors both ends |

## SAFETY

- The apparatus connects to a 110VAC outlet via a grounded plug. Observe all usual electrical safety precautions when operating. In particular:
- Do not use the apparatus if the cord or plug is damaged.
- Do not use the apparatus in a wet or damp environment.
- Do not defeat the grounding, which protects the user against dangerous external voltages in case of internal damage to the circuitry.
- Make all changes to the connections with the apparatus **unplugged** from the 110VAC outlet.
- Only operate the apparatus under responsible supervision by a technically qualified person.
- In use, the apparatus generates only low external voltages but very large currents, so the conductors quickly become hot. Since the demonstration requires only seconds to observe, there is no need for a prolonged operation. Do not operate the apparatus continuously for more than about 5 seconds. Do not touch the hot conductors until they have cooled (a few seconds)

## BACKGROUND

A schematic diagram of two conductors carrying currents $i_1$ and $i_2$ is shown in *Figure 2*. If we consider short elements of the conductors $\mathbf{ds_1}$ and $\mathbf{ds_2}$ a distance $\mathbf{r}$ apart, then Ampère (and others) showed in a series of careful experiments that the force $\mathbf{dF_1}$ which the element $\mathbf{ds_2}$ exerts on $\mathbf{ds_1}$ is given by:

$$\mathbf{dF_1} = (\mu_0 i_1 i_2/4\pi r^3).[\mathbf{ds_1}\times(\mathbf{ds_2}\times\mathbf{r})] \qquad (1)$$

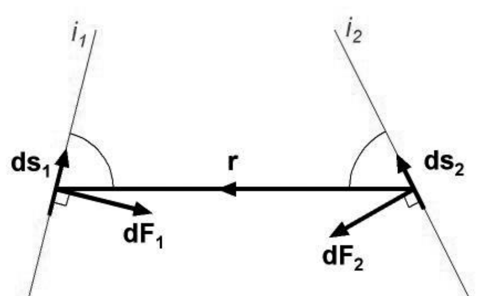

*Figure 2*

where $\mu_0$ is a constant.
But at a place where the magnetic induction is $\mathbf{B}$, a current-carrying element $\mathbf{ds_1}$ experiences a force $\mathbf{dF}$ which can be expressed simply by:

$$\mathbf{dF} = i_1.(\mathbf{ds_1}\times\mathbf{B}) \qquad (2)$$

Comparing equations (1) and (2), we can view the force on $\mathbf{ds_1}$ as generated by an induction $\mathbf{dB_2}$ created by the current $i_2$ in $\mathbf{ds_2}$. Then $\mathbf{dB_2}$ would be given by:

$$\mathbf{dB_2} = (\mu_0/4\pi r^3).i_2.(\mathbf{ds_2}\times\mathbf{r}) \qquad (3)$$

The magnetic field **H** is related to the induction **B** in free space by the equation:

$$\mathbf{B} = \mu_0\mathbf{H} \qquad (4)$$

It turns out that $\mu_0$ is the same constant discovered in equation (1), so by substitution

$$\mathbf{dH_2} = (i_2/4\pi r^3).(\mathbf{ds_2}\times\mathbf{r}) \qquad (5)$$

which is the well-known Biot-Savart Law for the magnetic field of a current element. Note that the strength of the field falls off as the inverse square of the distance from the element.

Referring again to *Figure 2*, we can see that if $\mathbf{ds_1}$ and $\mathbf{ds_2}$ are parallel to one another, the forces $\mathbf{dF_1}$ and $\mathbf{dF_2}$ are directed along **r** and will be equal in magnitude but opposite in sign. Each conductor can be regarded as experiencing a force due to the magnetic field of the other. Also, the forces between two parallel currents in the same direction are attractive, which is the opposite of electrostatic charges and magnetic poles, where like entities repel.

## DEMONSTRATION

### Preparation

- Check that the pointed ends of the conductors and the dimpled bearing contacts (see *Figure 3*) are clean and free of oxidation. If necessary, gently clean them by rubbing with a rough cloth.
- Insert the pointed ends of the conductors into the dimples in the top and bottom bearing contacts and check that the conductors swing freely. If they are too stiff or if they are not held by the bearing contacts, *gently* bend the copper end pieces until the fit and swing are satisfactory.
- Place the apparatus where the demonstration is to be made and level it by adjusting the three threaded feet under the base until the conductors remain in any position and show no tendency to swing together at any point.
- Using the connecting cords supplied, connect one of the circuits shown below and adjust the indicator arrows on each support pillar to show the current direction in each conductor.
- Plug the apparatus into a 110VAC outlet.

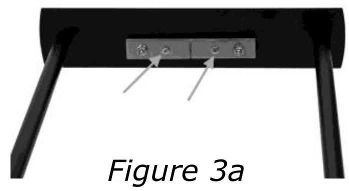

*Figure 3a*

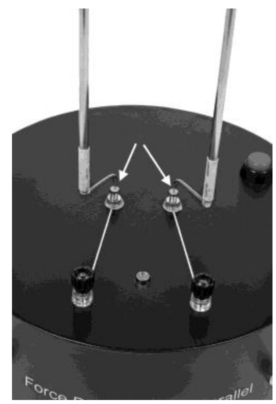

*Figure 3b*

*Parallel connection*
*Currents upwards*

*Parallel connection*
*Currents downwards*

*Antiparallel connection*
*Currents clockwise*

**Demonstration**

- Position the conductors so that the lever arms are approximately parallel.
- Keeping the hands well away from the conductors and contacts, press and hold the red pushbutton. The green indicator light between the two binding posts on the top of the base will illuminate to indicate that voltage is applied, and the conductors will immediately move either together or apart, depending on the mutual directions of the currents in each.
- DO NOT HOLD THE PUSHBUTTON DOWN FOR MORE THAN 5 SECONDS TO AVOID EXCESSIVE GENERATION OF HEAT IN THE CONDUCTORS AND THE TRANSFORMER.
- *Insulating boots at the ends of the conductors prevent metallic contact between the tubes and a consequent short circuit in the case where the conductors move towards each other.*
- Unplug the apparatus from the 110VAC outlet and connect a different circuit for a further demonstration.

## MAINTENANCE

*Figure 4*

- The Force Between Conductors Demonstrator needs no special maintenance except for the possible replacement of a burned-out fuse.
- The fuse will burn out in the case of an accidental short circuit between the supply binding posts due to an incorrect circuit connection or if the pushbutton is held down for an excessive time.
- The fuse is located on the bottom of the base (see *Figure 4*). Unplug the apparatus from the 110VA outlet before unscrewing the fuse cap. Replace the fuse with a 5 x 20 mm miniature fuse rated at 250V/3A. DO NOT USE A HIGHER-RATED FUSE to avoid damage to the apparatus.
- Store the apparatus in a cool, dry place away from sunlight.