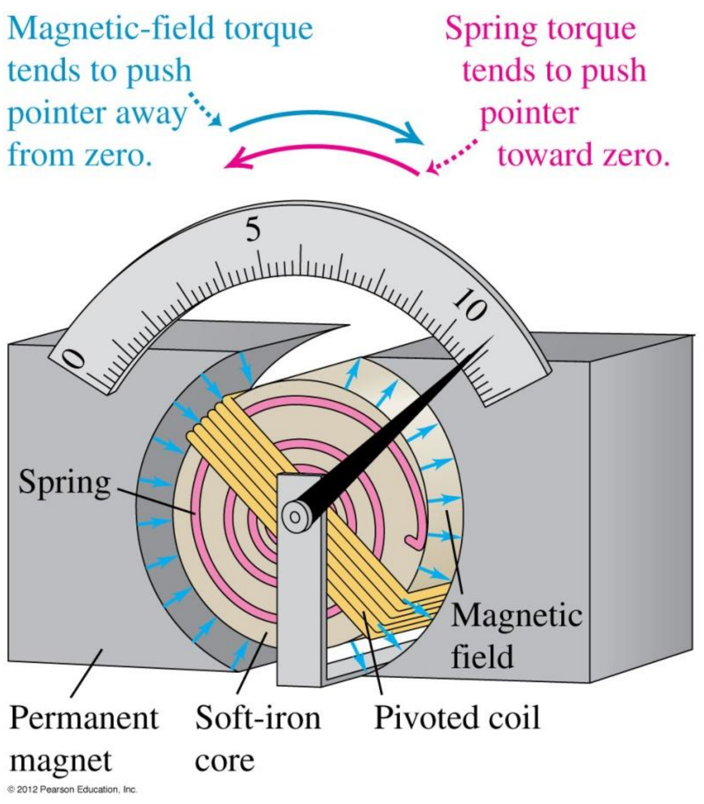
Lecture 25
(Electrical Measuring Instruments)

Physics 161-01 Spring 2012

Douglas Fields

Galvonometer

- We haven't yet discussed magnetic fields, but we need to use them without explanation for now.
- When a current-carrying coil of wire is placed in a magnetic field, there is a torque created that tends to rotate the coil.
- If we place a coil in a permanent magnetic field (say, outside a magnet), the torque on the coil will be proportional to the current.
- A spring attached to the coil gives a torque counter to that one, and returns the coil back to its starting position in the absence of a current.
- A needle attached to the coil gives an accurate reading of the rotation of the coil.



A Galvonometer as an Ammeter

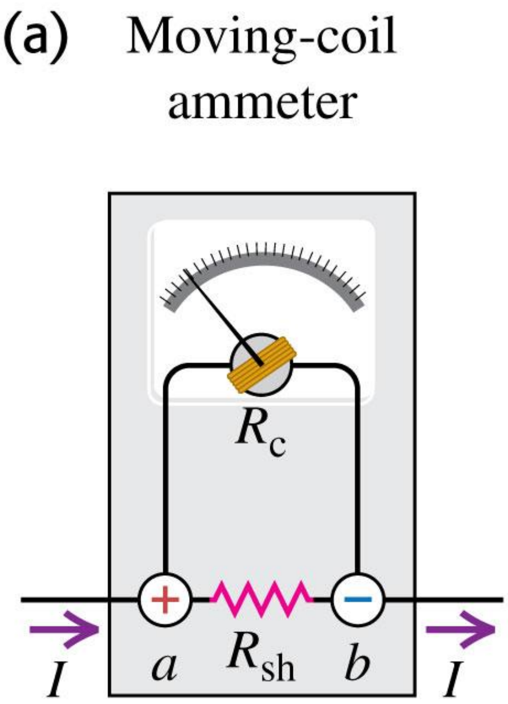
- The full-scale deflection of the coil occurs at some current which we will call I_{fs}.
- Now, the coil itself has some resistance, R_c, so: $V_{fs} = I_{fs}R_c$.
- Now, suppose that we want to make an instrument that will give full deflection when it is connected in series in a circuit with 1A of current.
- If we add a resistor (known as a shunt resistor, R_{sh}) in parallel to the coil, with an appropriate value, we can control the flow of charge such that when there is 1A of current going through point a, I_{fs} goes through the coil.
- Note that the potential across the coil and the potential across the shunt resistor are the same, so we have:

$$V_{ab} = I_{fs}R_c = \left(I_a - I_{fs}\right)R_{sh}$$

- For instance, if we have a coil with resistance 20Ω and full scale deflection current of 1mA, one would need a shunt resistor of 0.02Ω.
- Then, the equivalent resistance of the ammeter would be:

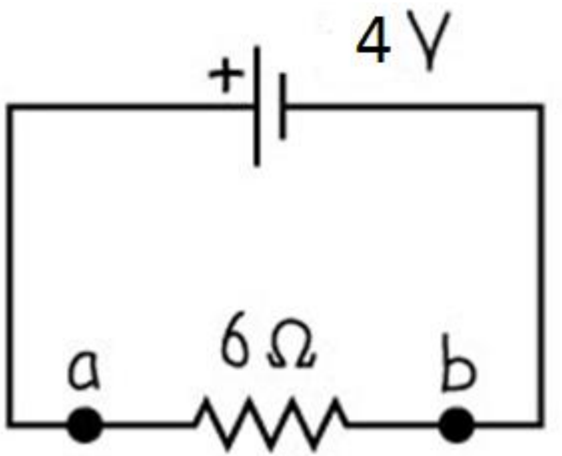
$$\frac{1}{R_{eq}} = \frac{1}{R_{sh}} + \frac{1}{R_c} = \frac{1}{0.02\Omega} + \frac{1}{20\Omega} \Rightarrow$$

$$R_{eq} \approx 0.02\Omega$$



A Galvonometer as an Ammeter

- Note that until now, we have considered ammeters to have *zero* resistance.
- Since this is not the case in reality, we have to take this into account when we place an ammeter into a circuit.
- Let's consider two different circuits:



$$V_{ab} = 4V = IR = I\left(6\Omega\right) \Rightarrow$$

$$I = 0.667A$$

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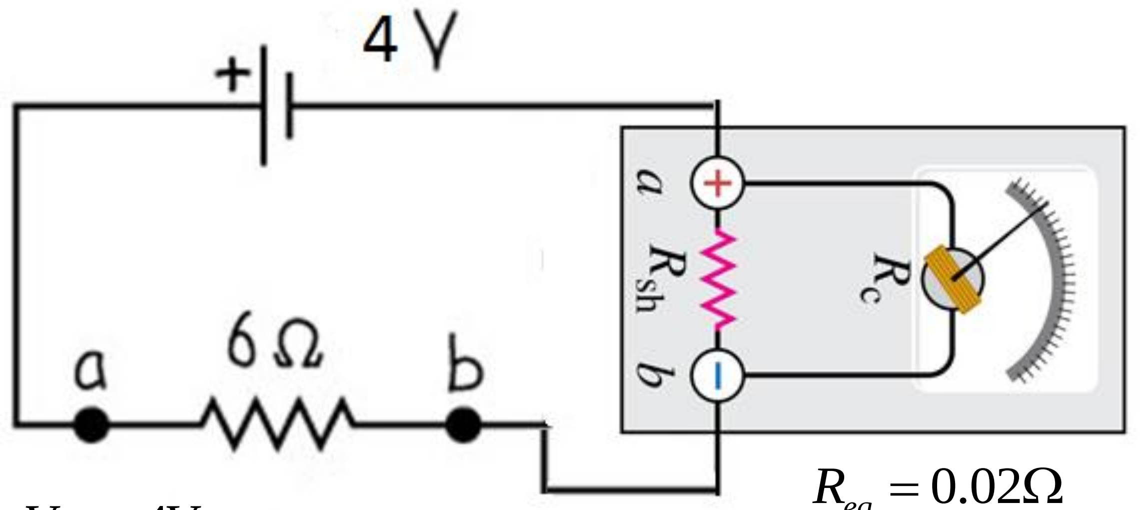


$$R_{eq} = 0.02\Omega$$

$$V_{ab} \neq 4V$$

$$4V - I\left(6\Omega\right) - I\left(0.02\Omega\right)$$

$$I = 0.664A$$

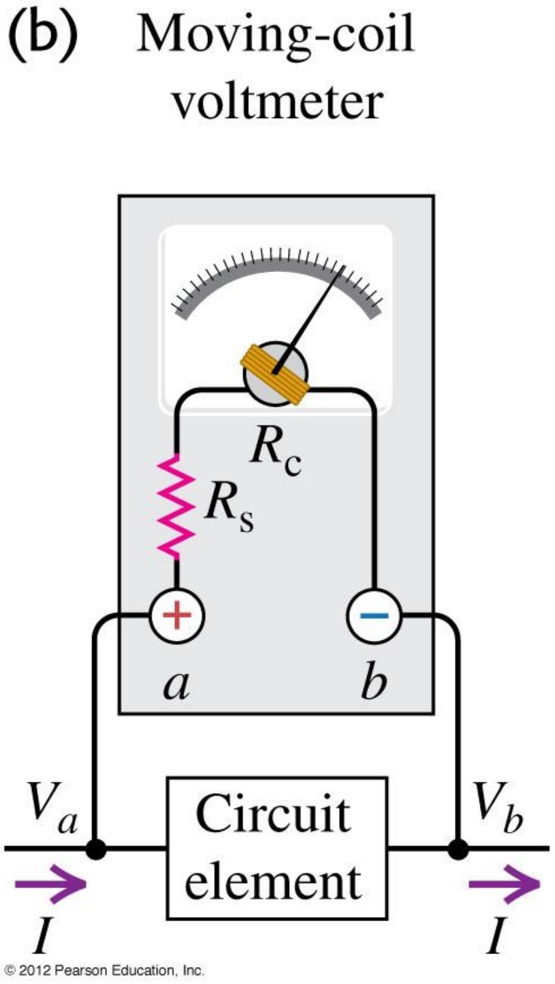
A Galvonometer as an Voltmeter

- Now, suppose that we want to make an instrument that will give full deflection when it is connected in parallel to a circuit element with 1V potential difference across it.
- If we add a resistor (known as a shunt resistor, R_{sh}) in series with the coil, with an appropriate value, we can control the flow of charge such that when there is 10V across the shunt resistor – coil combination, I_{fs} goes through the coil.

$$V_{ab} = I_{fs}\left(R_{sh} + R_c\right)$$

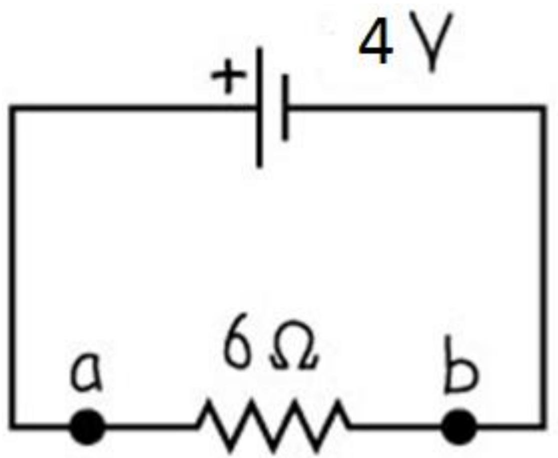
- For instance, if we have a coil with resistance 20Ω and full scale deflection current of 1mA, one would need a shunt resistor of 9,980Ω.
- Then, the equivalent resistance of the voltmeter would be:

$$R_{eq} = R_{sh} + R_c = 9980\Omega + 20\Omega \Rightarrow$$
$$R_{eq} = 10k\Omega$$



A Galvonometer as an Voltmeter

- Note that until now, we have considered ammeters to have *infinite* resistance.
- Since this is not the case in reality, we have to take this into account when we place an voltmeter into a circuit.
- Let's consider two different circuits:



$$V_{ab} = 4V = IR = I\left(6\Omega\right) \Rightarrow$$
$$I = 0.667A$$

A Galvonometer as an Voltmeter

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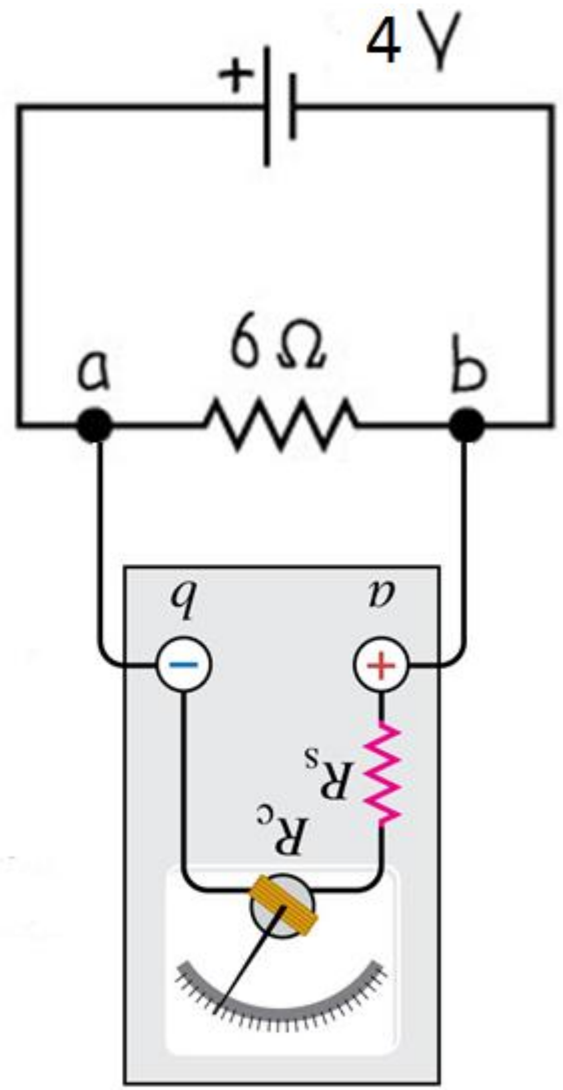

$$\frac{1}{R_{eq}} = \frac{1}{R_{volt}} + \frac{1}{R} = \frac{1}{10k\Omega} + \frac{1}{6\Omega} \Rightarrow$$

$$R_{eq} = 5.996\Omega$$

$$V_{ab} = 4V = I\left(5.996\Omega\right) \Rightarrow$$

$$I = 0.66707A$$

CPS 25-1

You wish to study a resistor in a circuit. To simultaneously measure the current in the resistor and the voltage across the resistor, you would place

A. an ammeter in series and an voltmeter in series.

B. an ammeter in series and an voltmeter in parallel.

C. an ammeter in parallel and an voltmeter in series.

D. an ammeter in parallel and an voltmeter in parallel.

CPS 25-1

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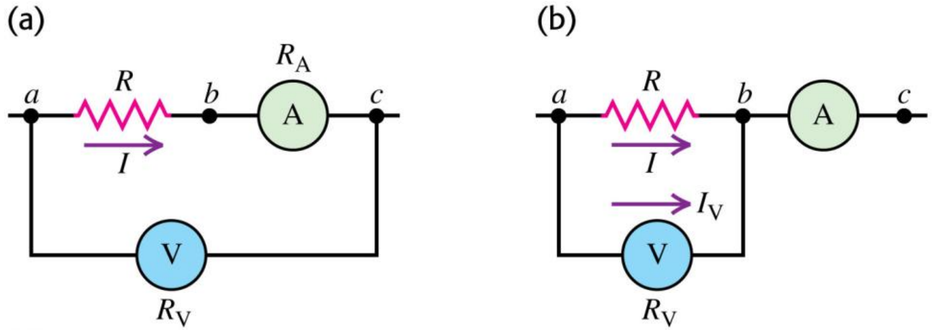
Measuring Resistance

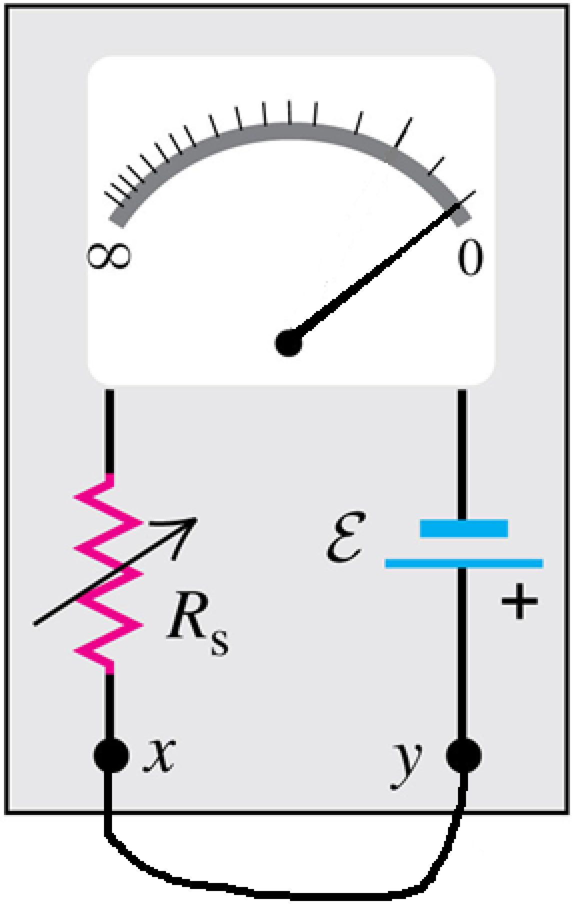
- Now, if you want to measure the resistance of a resistor, you could use both an ammeter and a voltmeter together in a circuit:



- However, because the ammeter affects the voltage drop across the resistor, and the voltmeter affects the current through the resistor, there is no combination of the two that leaves the circuit unchanged, and therefore the measurement of the voltage across and current through will be inaccurate.

A Galvonometer as an Ohmmeter

- However, once again, we can use a galvonometer to solve our problem.
- If you put an EMF and a variable resistor in series with a galvonometer, and then…
- … adjust the shunt resistor until the current through the galvonometer puts the needle at full scale…



$$\mathcal{E} = \left(R_c + R_{sh}\right) I_{fs}$$

A Galvonometer as an Ohmmeter

- ...then insert the resistor that you want to measure in series, the current will drop by:

$$I_{fs} = \frac{\mathcal{E}}{(R_c + R_{sh})} \Rightarrow$$

$$I = \frac{\mathcal{E}}{(R_c + R_{sh} + R)}$$

- Note that this goes as 1/R, so it is not linear, hence the non-linear scale.