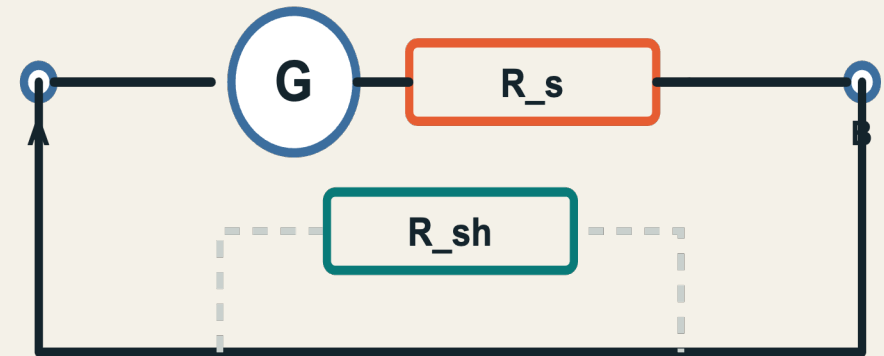


Voltmeters & Ammeters

How one sensitive movement becomes two measuring instruments

Essential question

Why does a voltmeter need a large resistance, while an ammeter needs a small one?



series or parallel changes the instrument

The measurement goal determines the structure

Begin with the same galvanometer movement; change the current path.

01

LIMIT

A movement tolerates only a small full-scale current.

02

VOLTAGE

Add series resistance to limit current.

03

CURRENT

Add a parallel shunt to bypass current.

04

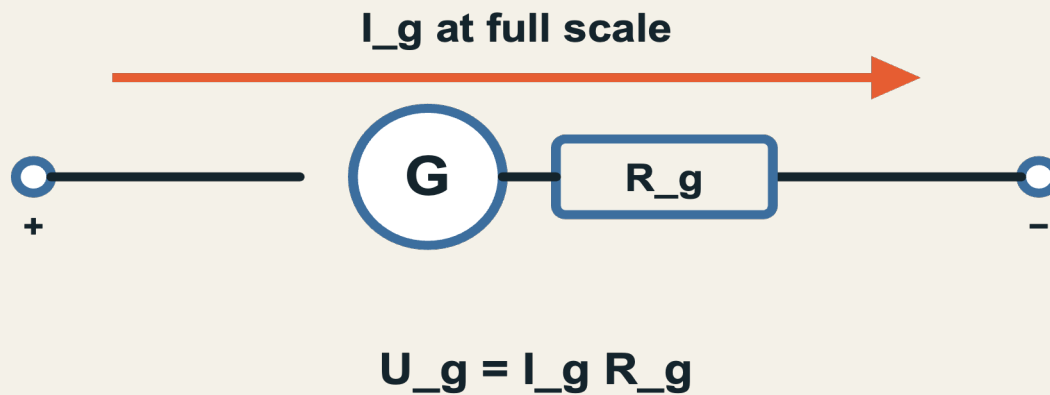
RANGE

Select resistance to set the full-scale value.

The circuit must protect the movement at full scale.

A galvanometer is sensitive – and limited

Its movement reaches full-scale deflection at a small current I_g .



Three movement parameters

I_g full-scale current

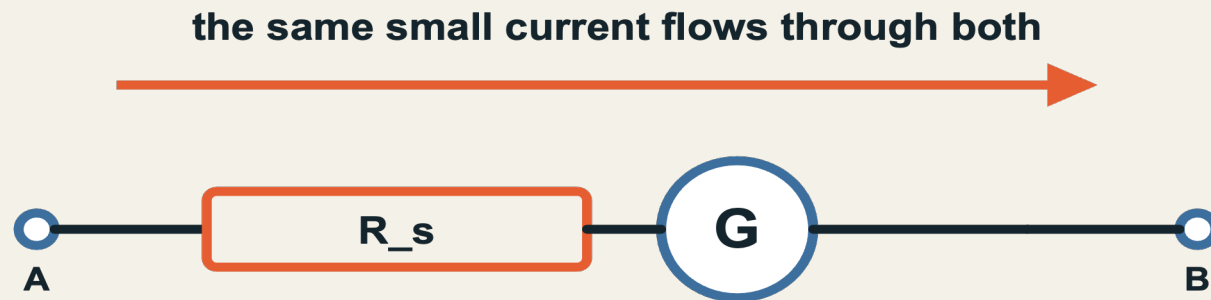
R_g internal resistance

U_g $I_g R_g$ at full scale

CONVERT

A voltmeter adds resistance in series

The multiplier resistor takes most of the applied voltage.



$$V = I_g (R_s + R_g)$$

Design goal

limit current to I_g

make input resistance large

Connect the finished voltmeter in parallel.

DERIVE

The series resistor sets the voltage range

At the chosen full-scale voltage V , the movement current must equal I_g .

$$V = I_g (R_s + R_g)$$

$$R_s = V / I_g - R_g$$

RANGE MULTIPLIER

$$n = V / U_g$$

$$R_s = (n - 1) R_g$$

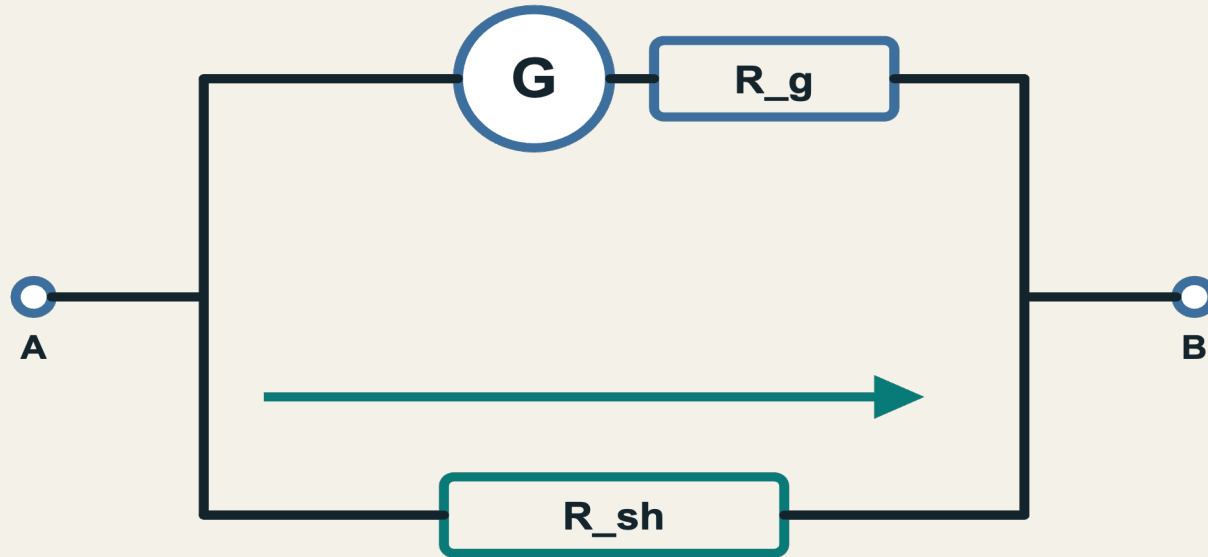
$$R_V = R_s + R_g = n R_g$$

Larger voltage range → larger series resistance

CONVERT

An ammeter adds a low-resistance shunt

The movement carries I_g ; the shunt carries the rest.



most current bypasses the movement

At full scale

$$I = I_g + I_{sh}$$

same voltage
across both branches

Connect the finished ammeter in series.

DERIVE

The shunt sets the current range

Parallel branches share the same voltage.

$$I_g R_g = (I - I_g) R_{sh}$$

$$R_{sh} = I_g R_g / (I - I_g)$$

RANGE MULTIPLIER

$$n = I / I_g$$

$$R_{sh} = R_g / (n - 1)$$

$$R_A = R_g / n$$

Larger current range → smaller shunt resistance

The two conversions have opposite design goals

Series limits current; parallel redirects current.

VOLTMETER

series multiplier

large internal resistance

parallel connection to circuit

AMMETER

parallel shunt

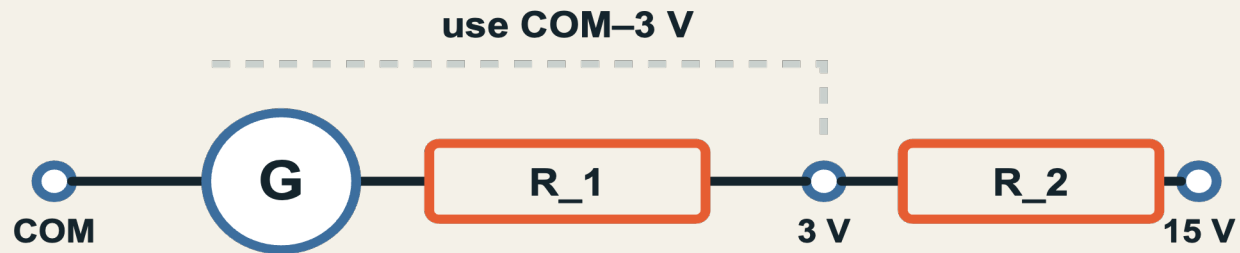
small internal resistance

series connection to circuit

EXTEND

A multi-range voltmeter selects series resistance

Higher-voltage terminals include more resistance in the current path.



use COM–15 V: current also passes through R₂

Range rule

higher range



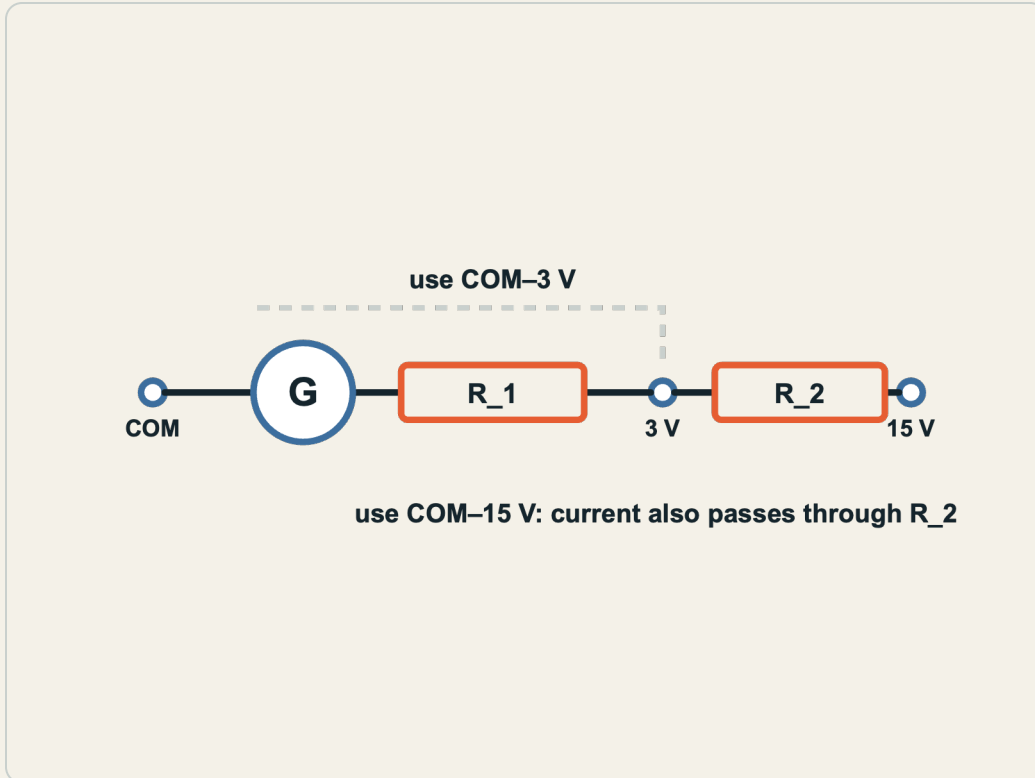
more series resistance

Always start on the highest range.

APPLY

Worked example: design two voltage ranges

Movement: $I_g = 100 \mu\text{A}$, $R_g = 500 \Omega$. Design 3 V and 15 V ranges.



3 V range

$$R_1 = 3 / 100 \mu\text{A} - 500$$

$$R_1 = 29.5 \text{ k}\Omega$$

15 V range

$$R_2 = 15 / 100 \mu\text{A} - 500 - R_1$$

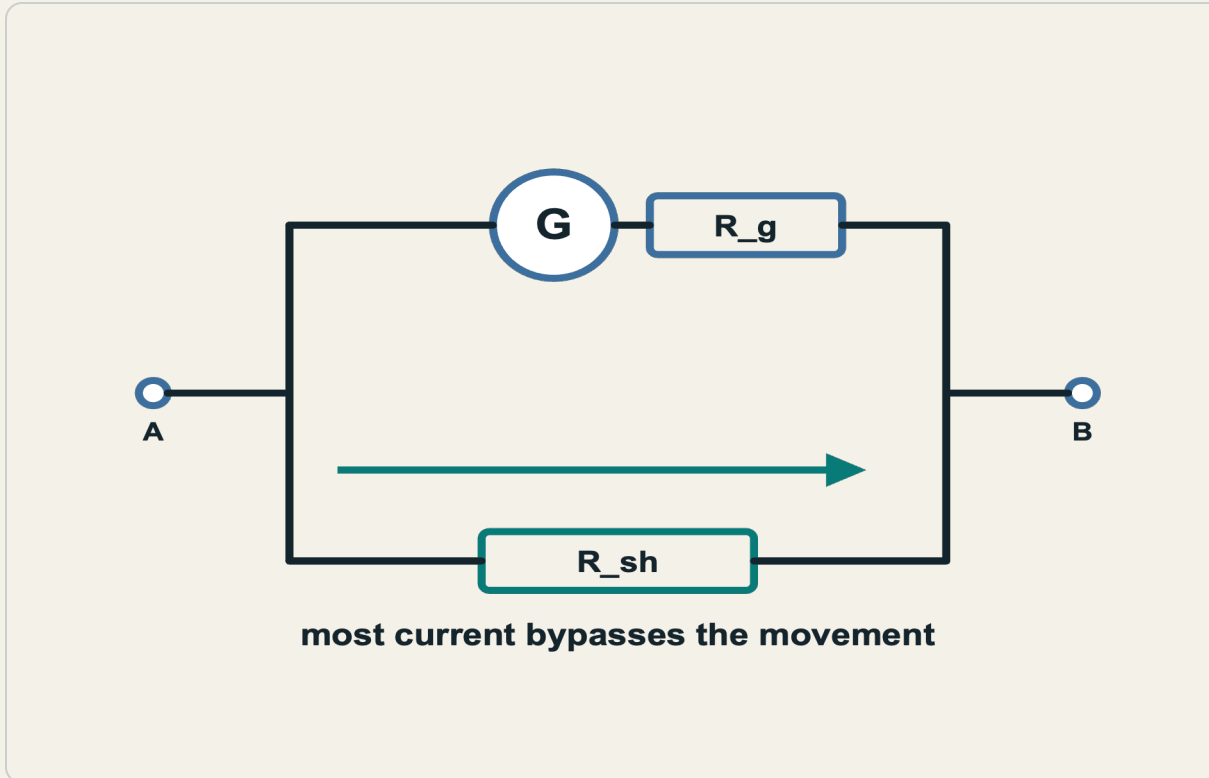
$$R_2 = 120 \text{ k}\Omega$$

Both ranges still drive exactly I_g at full scale.

APPLY

Worked example: design a current shunt

Movement: $I_g = 10 \text{ mA}$, $R_g = 50 \ \Omega$. Design a 1.0 A range.



$$R_{sh} = I_g R_g / (I - I_g)$$

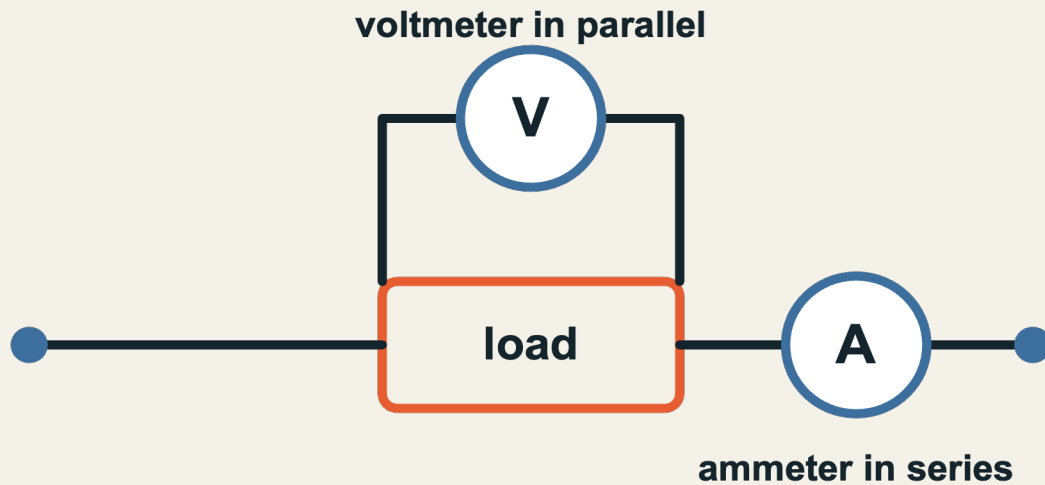
$$= 0.010 \times 50 / (1.0 - 0.010)$$

$$R_{sh} \approx 0.505 \ \Omega$$

About 99% of the current bypasses the movement.

Correct connection protects the circuit and the meter

Real meters also change the circuit they measure.



Voltmeter

parallel • high R
finite current causes loading

Ammeter

series • low R
voltage drop causes loading

Wrong connection can overload the movement.

The circuit structure explains the instrument

Protect the movement, choose the range, then connect correctly.

VOLTMETER

series R_s

large R_V

connect in parallel

AMMETER

parallel R_{sh}

small R_A

connect in series

EXIT TICKET | To increase an ammeter's range, should the shunt resistance increase or decrease?