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50.0 Shades of Multimeters

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Multimeters

Multipurpose:

Voltmeter (voltage)

Ampermeter (current)

Ohmmeter (resistance)

...

Main multimeter types

Analog (scale reading)

Digital manual ranging

Digital autoranging

Analog multimeter

Digital multimeter (DDM)

Autoranging

Digital multimeter (DDM)

Manual ranging

Ranges - Functions

- DCV - DC Voltages
- ACV - AC Voltages
- DCA - DC Current
- ACA - AC Current
- OHM – Resistance
- hFE - Transistor test
- f - Frequency
- ♫/diode – Continuity/Diode test
- CAP - Capacitance

Ranges

Range – maximum value that can be measured

DCV:

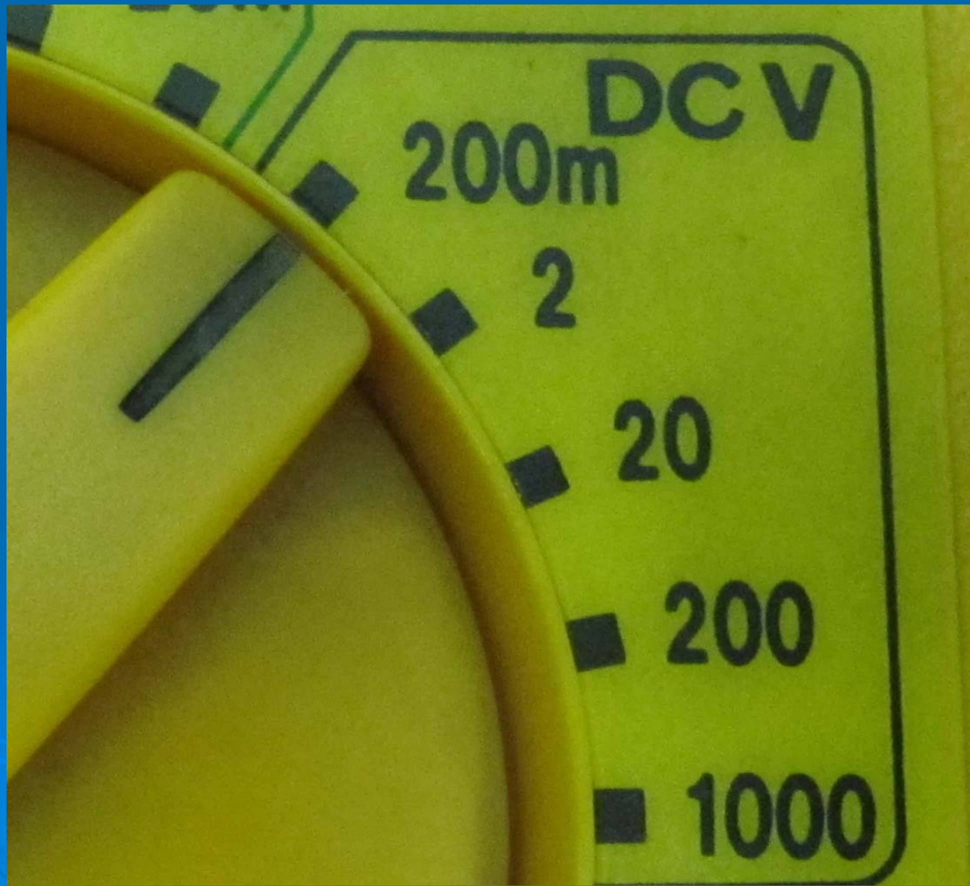
200 mV

2 V

20 V

200 V

1000 V



Ranges

If you don’t know the approximate value of the measured quantity, always start from the highest available range!

Best possible range for your measurement – measured value must be as close as possible to the top of that range.

Ranges

Let's measure
9 V battery.

Start from
1000 V range.

It shows
009 or 9 V.

Ranges

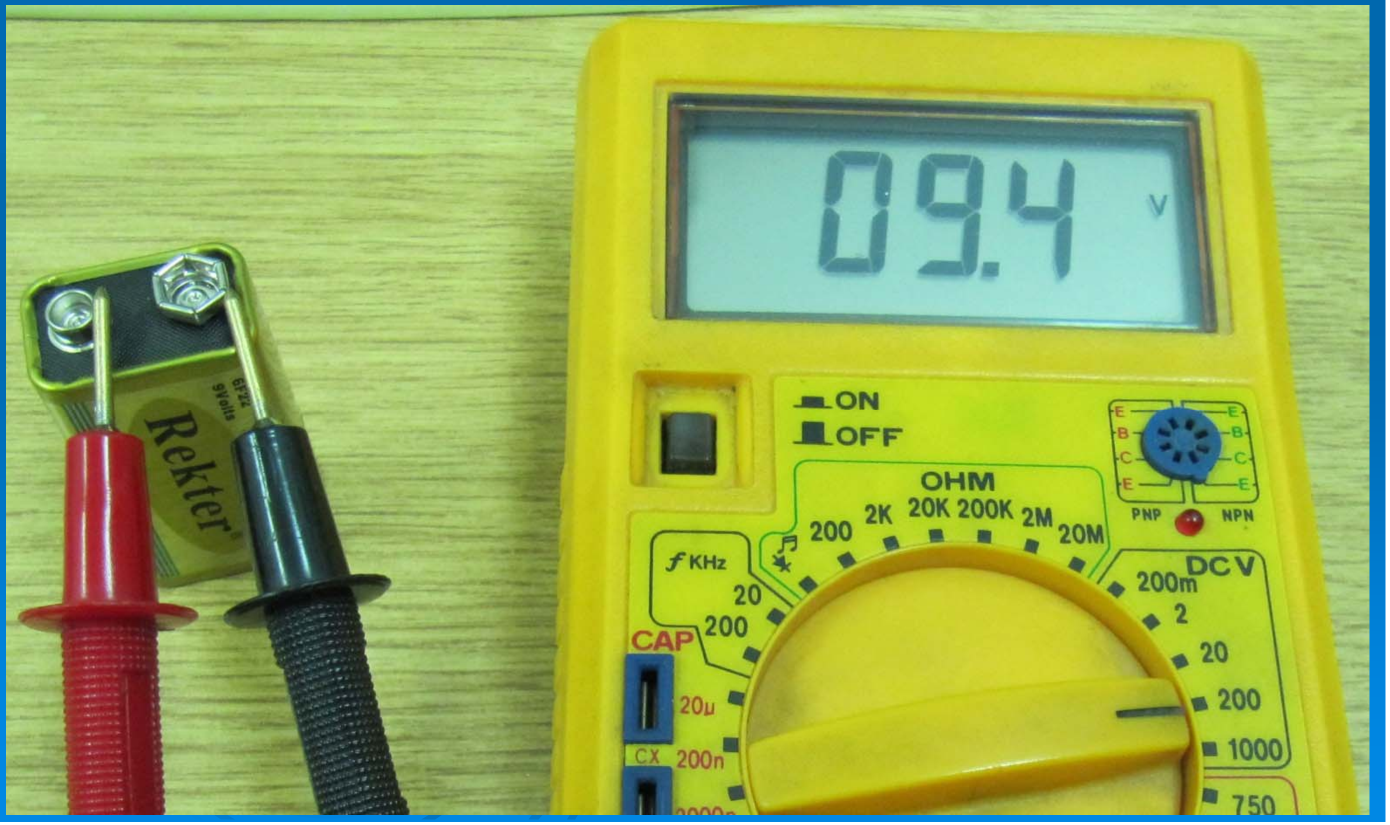
So you now know the approximate value!

You can range down one notch, or skip directly to the best possible range for this value, in this case 20 V.

Ranges

200 V range shows 09.4 or 9.4 V.

Now we have more accuracy, we know one decimal point. Still, we can get a better reading...



Ranges

20 V range shows 9.39, meaning 9.39 V.

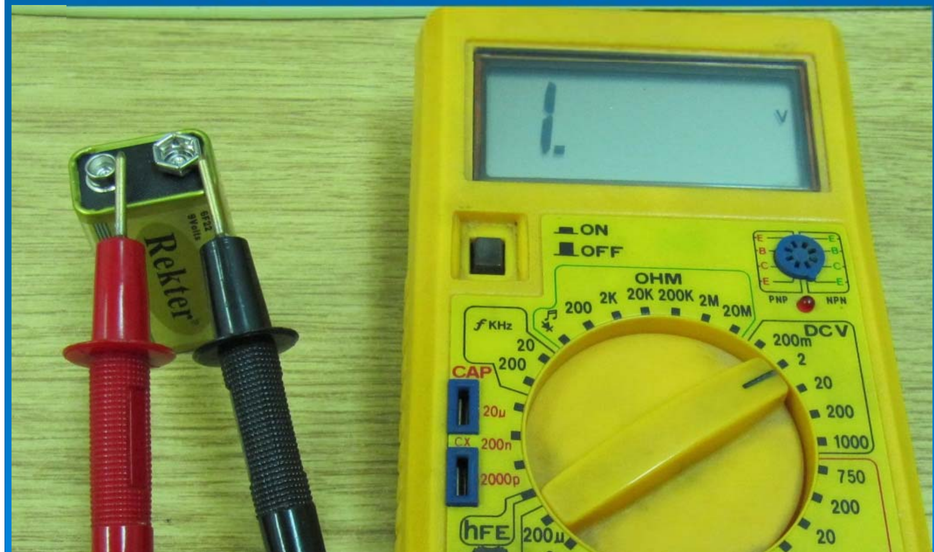
This is the best range for this voltage, you get two decimal points, and the best reading.

Ranges

2 V and 200 mV ranges displays 1.

1 at the right corner of display means measured value is OVERRANGE!

You can’t measure 9 V at these ranges.



Maximum values for these ranges are 2 and 0.2 V.

Ranges

Hey, that's confusing! ☹

Let's see...

As ranges get smaller, you can measure lower values BUT you get more decimal places! So, it get's more accurate?

Yes and No! This is not accuracy, rather the resolution, that stays the same.

More on accuracy and precision later...

Accuracy, resolution, bits...

Number of digits

Maximum reading on display

3 ½ bits – 1999

3 ¾ bits – 3999

4 ½ bits – 19999

5 ½ bits – 199999

6 ½ bits – 1999999

Resolution and bits...

For display with 3 ½ bits maximum reading is 1999. There is max of 1999 counts.

One count is the smallest bit of measured value it can differenciate, or the smallest change in value it can display.

Resolution is the smallest value of that count, dependent on the range used.

Resolution and bits...

At 200 mV range, max reading is 199.9 mV, resolution is 199.9/1999 = 100 µV = 0.1 mV

2 V – 1999 mV, resolution 1 mV

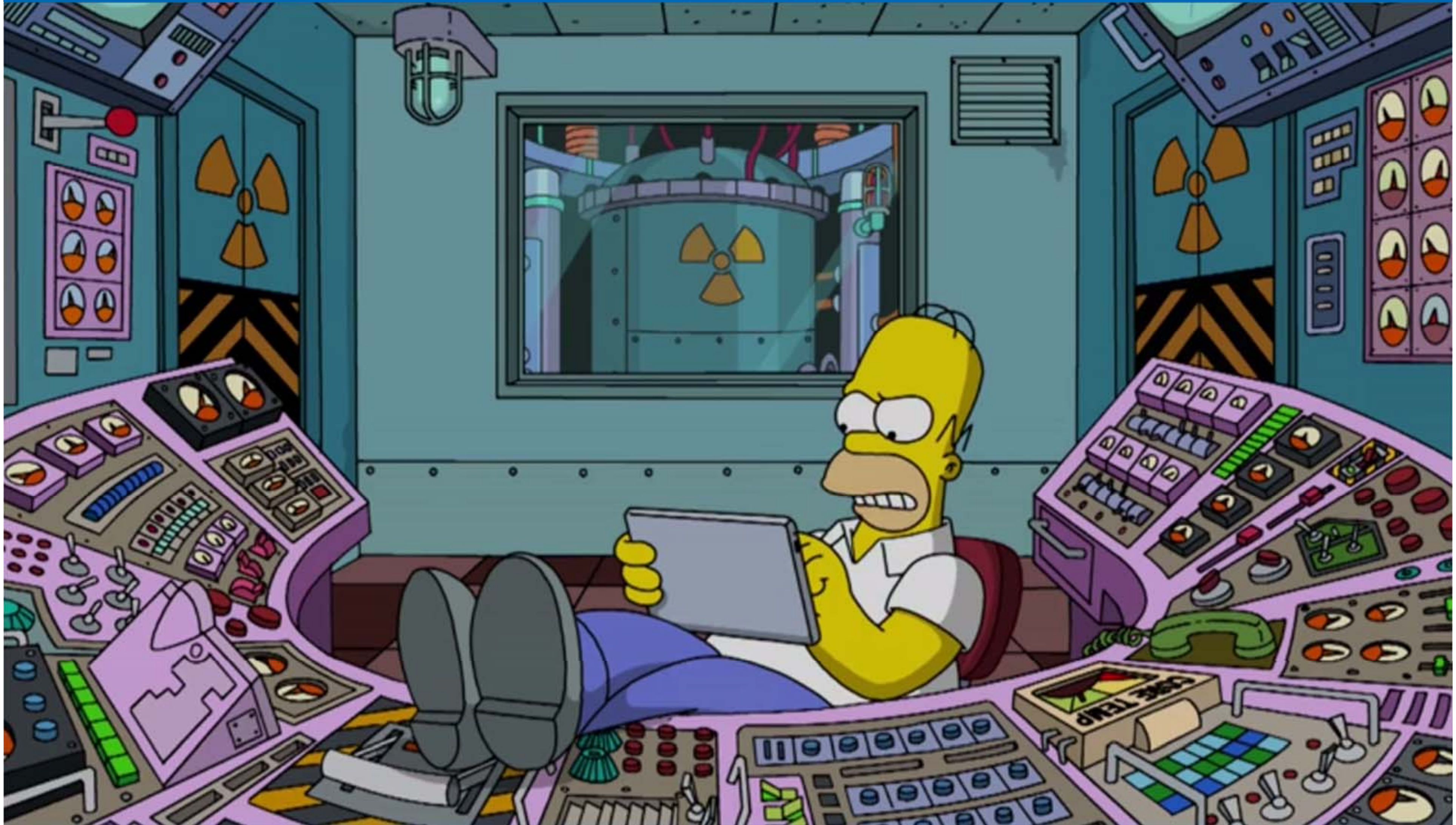
20 V – 19.99 V, resolution 10 mV or 0.01 V

200 V – 199.9 V, resolution 0.1 V

1000 V – 1999 V, resolution 1 V

(it can display 1999 V, but this multimeter can safely measure only up to 1000 VDC!)

OK, but let’s measure...



Probes and inputs

On this multimeter, there are 4 inputs:

20 A – DC/AC current ranges of 20 Amps only (unfused!)

A – all DC/AC current ranges up to 200 mA (fused!)

V/Ω – for DC/AC Voltages and Resistance

COM - Common (or „Ground“ or „minus“) input, all values are referenced to it.

Probes and inputs

Insert black probe into COM input.

From now on, it stays in the same place.

Red probe (or „Postive“ or „plus“) goes into one input, depending on what you are going to measure.

Measuring DCV

Black probe into COM.

Red probe into V/Ω.

Power ON.

Measuring DCV

If high voltages can be expected, turn range to maximum. If only low voltages are present, overrange won’t be a problem if you miss the right range.

Most low power DC electronics use voltages below 20 V, so start there.

WARNING!

DO NOT change range functions while both probes are connected to anything!

You can switch thru ranges within one function while measuring „live“, eg. from 1000 V to 200 mV.

BUT don’t switch from voltage to resistance, or current, or from current to resistance or voltage while doing measurement!

WARNING!

Always first lift one probe from the circuit, switch to new range function AND change the probe input if needed.

If not, you will BURN the multimeter and/or measured device!

Think twice before changing to Resistance or Current ranges.

WARNING!

Cheaper multimeters have poor or no protection whatsoever from such mistakes. They can even explode if used incorrectly.

You can burn fuse or the whole multimeter, or hurt yourself.

So DON'T measure AND change range functions at the same time.

Measuring DCV

When measuring voltages, you connect the probes in PARALLEL to the voltage source or observed component!!!

Mnemonic to remember:

Measuring voltages – hands in front of you!

Measuring DCV

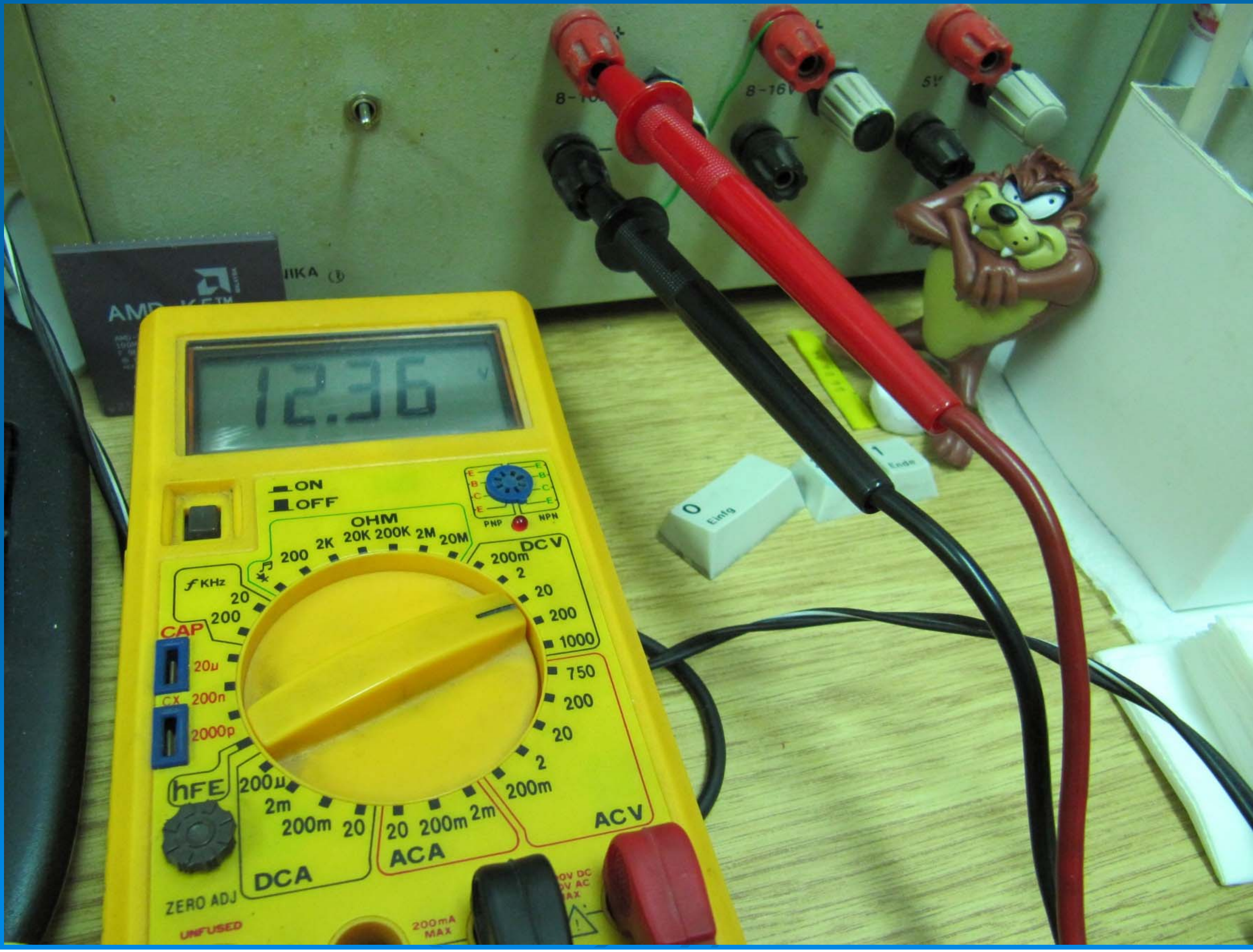
Connect black probe to ground (GND) or 0 voltage point.

Red probe to voltage point being measured.

If reversed, negative voltages will be displayed.

If negative voltages are read in normal position, then measured voltage is indeed negative.

Measuring DCV



Measuring PC-ATX PSU

Measuring PC-ATX PSU

Declared value	Measured value
+12 V @ 16 A	+11.68 V
-12 V @ 0.5 A	-12.19 V
+5 V @ 30 A	+5.09 V
-5 V @ 0.5 A	-4.87 V
+3.3 V @ 30 A	+3.28 V
+5 V USB @ 0.5 A	+4.92 V

Measuring PC-ATX PSU

Wait, so USB isn’t superdupermegagiga ultimate source of +5 V??! How could it be?

USB specs state +5 V +/- 5 %, or +5 V +/- 0.25 V, meaning voltage must be in the range of 4.75 – 5.25 V!

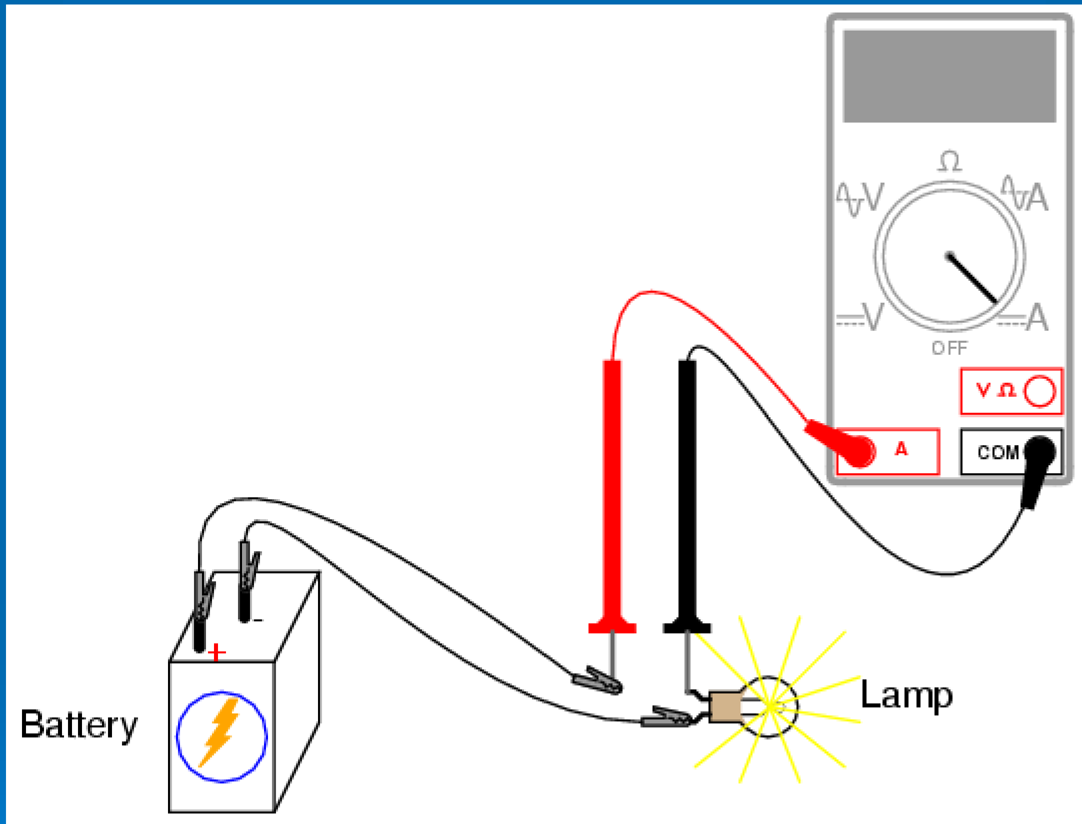
So no, nothing is perfect! (women and electronics especially)

Measuring DCA

When measuring current, always connect probes in SERIES with measured component!

NEVER EVER in parallel like for voltage, or you'll make short-circuit and put maximum available current from source thru the meter. Multimeter now acts as ampermeter and has very low resistance.

Measuring DCA



Measuring DCA

Mnemonic to remember:

When measuring current, put your arms in letter T position, to remember to make a break in the circuit and then measure it.

So, measuring currents is very risky biz.

Be VERY, VERY careful.

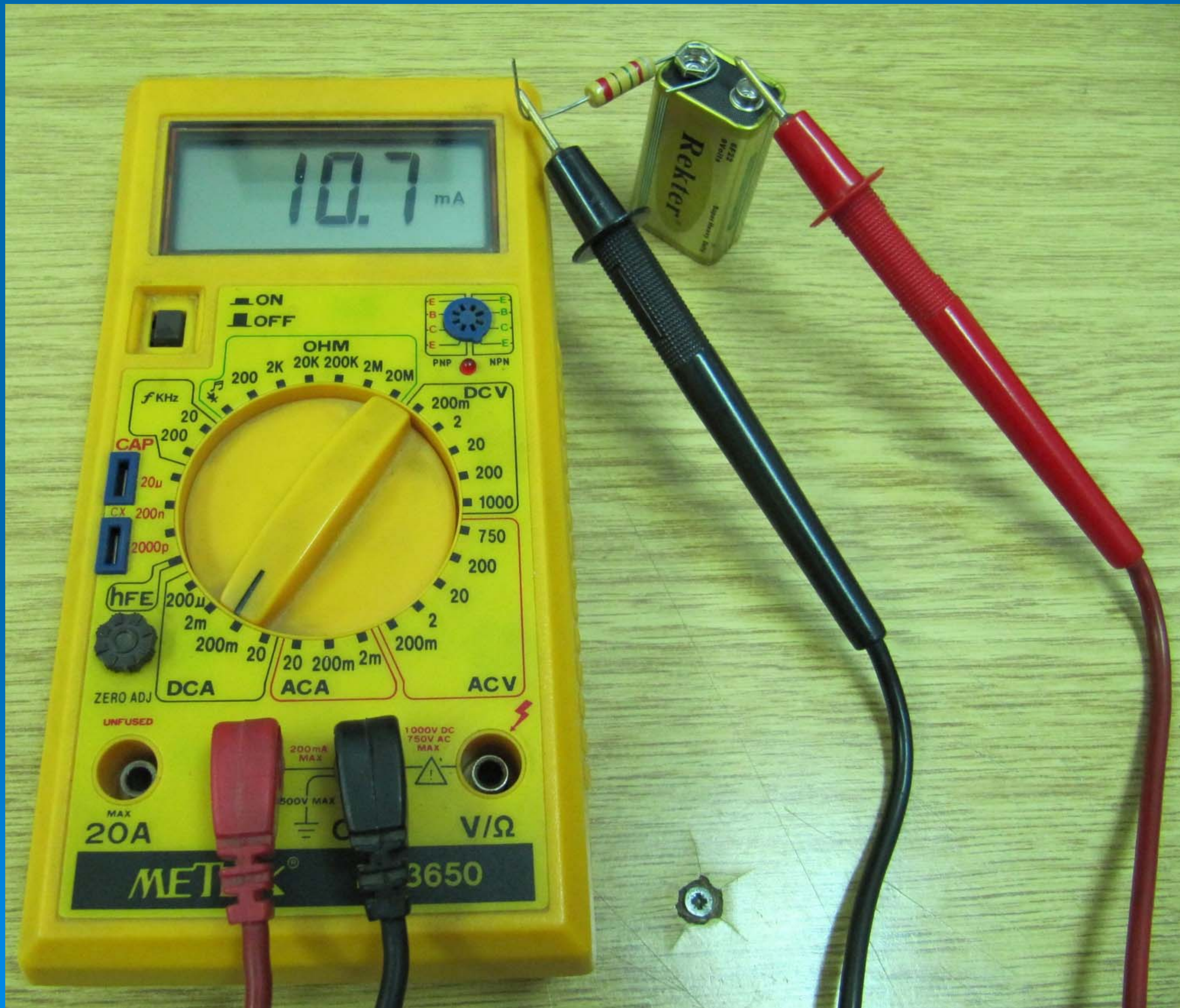
Measuring DCA

Connect red probe to point where current leaves the circuit at the start of the break.

Black probe goes to other side, where current enters back in the circuit.

If reversed, negative values will be displayed.

Measuring DCA



Measuring DCA

If not sure what currents you might get, ALWAYS test it at maximum range!

Put red probe into 20 A input and switch to 20 DCA range.

In this range, all measurements must be made as quick as possible, as large currents heat up the instrument and can damage it, if measured for periods longer than 10 seconds.

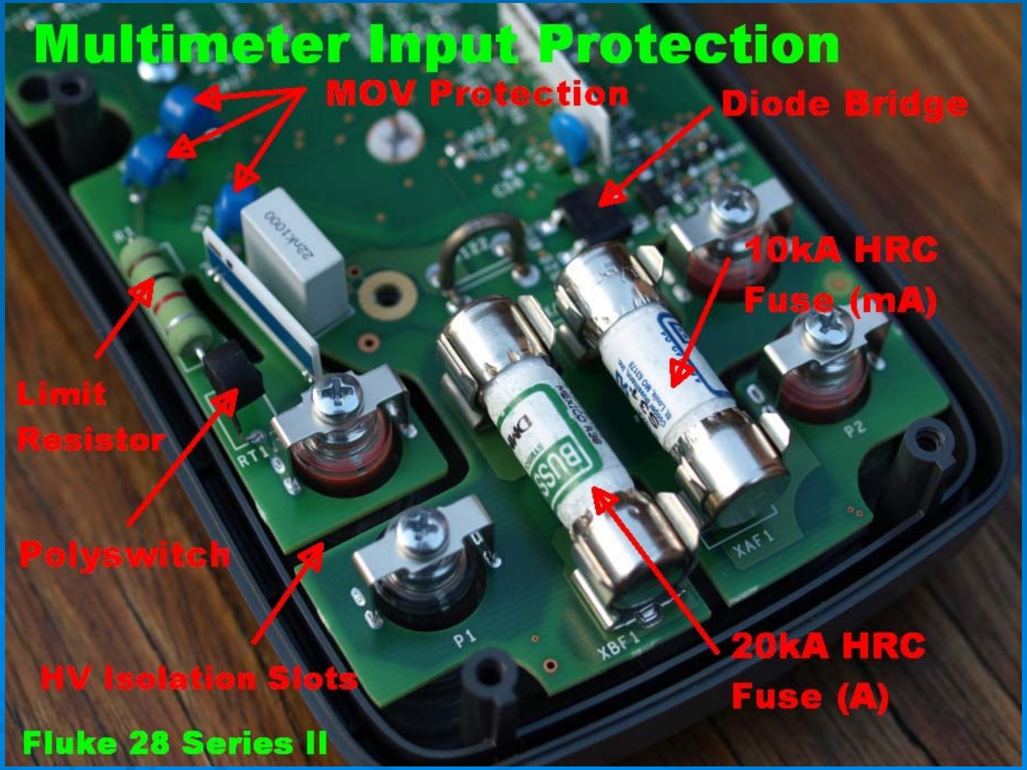
Measuring DCA

If the reading is below 0.2 A, lift the probes, change red probe to A/mA input, switch to 200 mA range and measure again.

Measuring DCA

200 mA and lower ranges have electric fuse protection. It will burn if you put more than 200 mA thru it, but it will protect the meter.

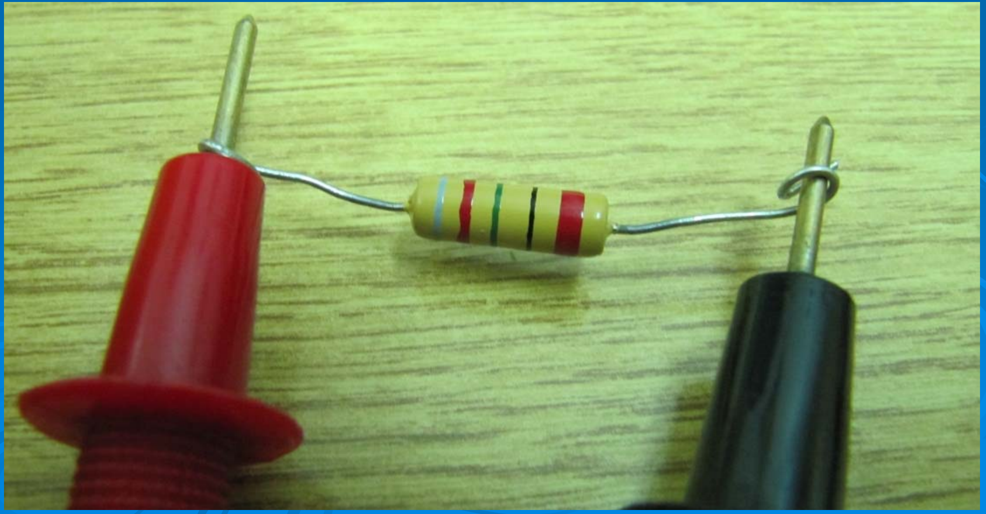
You can replace the fuse, and it should work again.



Measuring OHMS

When measuring resistance, ALWAYS remove the power from device you are measuring.

This is the most common mistake and easiest way to destroy your meter permanently.



Measuring OHMS

Also, don’t measure resistors inside circuits, you won’t get proper value. Other components affect the resistance also.

In this mode, meter produces some small mA current thru the probes. Some sensitive parts not meant to have resistance measured can be damaged in this case...

Measuring OHMS

So, measure just free resistors.

Mnemonic to remember:

When measuring Resistance, put your hands close to the chest, meaning: measure that small resistor only, not that mounted in some circuit.

And don’t measure resistance while there is voltage present on it!

Measuring OHMS

Move red probe back to V/Ω input, switch to any resistance range (you can't burn it) and measure the resistor.

Measuring OHMS

2M and 20M ranges display values in MegaOhms.

2K, 20K and 200K ranges display KiloOhms.

200 range display Ohms.

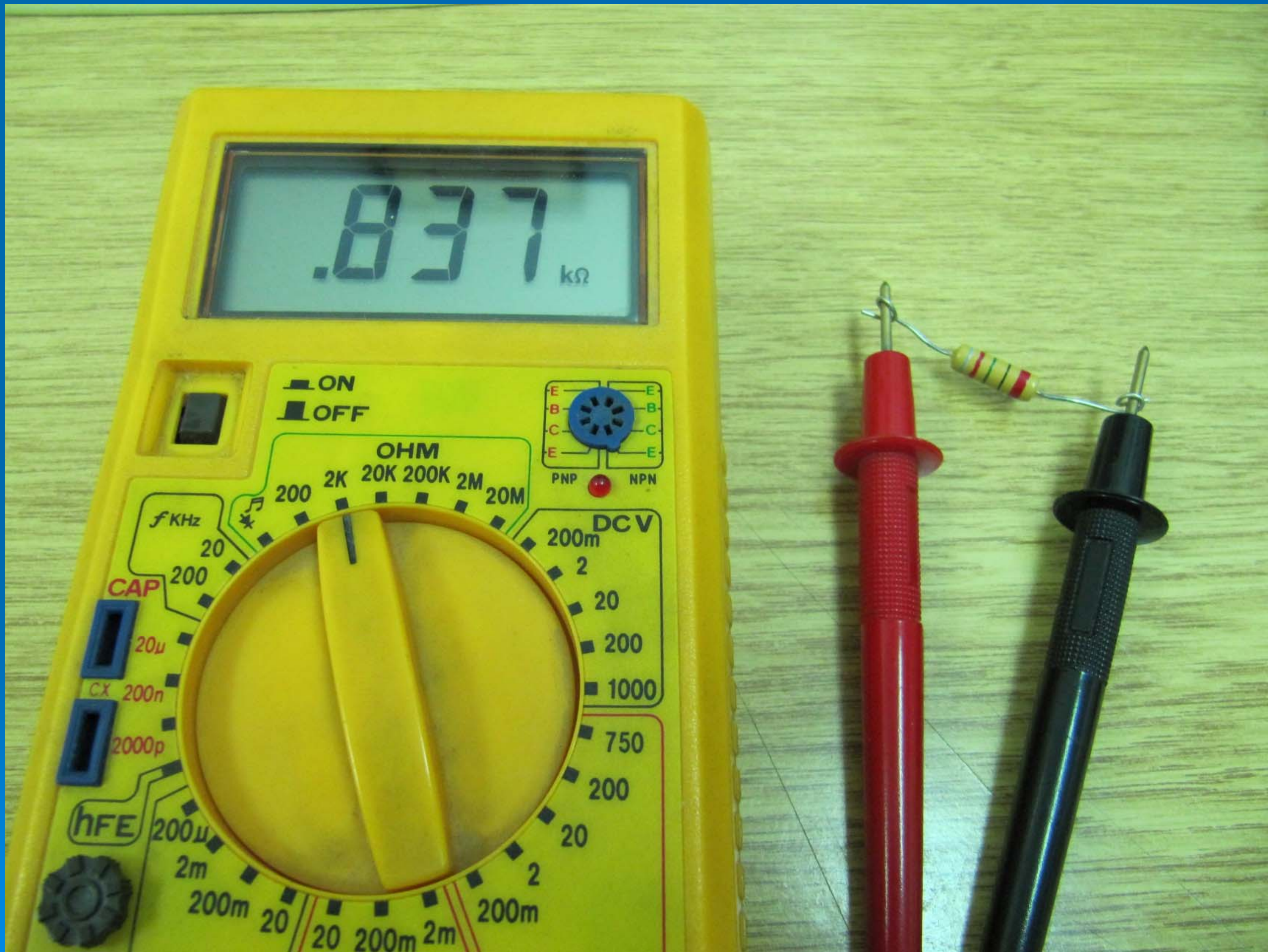
Measuring OHMS

When measuring resistance, it's not important what probe goes to which end.

Resistor resistance is the same, regardless of the current orientation.

Resistors are temperature dependent. When using meters with more digits, you can see how the resistance slightly changes while you hold it with your fingers, body heat is being transfered and resistance changed, around 0.01% for 1°C

Measuring OHMS



Measuring OHMS

If you hold the resistor with both hands, you're connecting your body resistance in parallel to it. You won't get hurt, and it won't affect small resistor values, but you'll get large errors for MΩ resistors.

So best practice is not to touch metal ends on probes during measurements.

WARNING!

DO NOT touch metal ends on probes during Voltage and Current measurements.

AC and high DC voltages can kill you.

Even small AC and DC currents can kill you.

AC values

Measuring AC values is tricky.

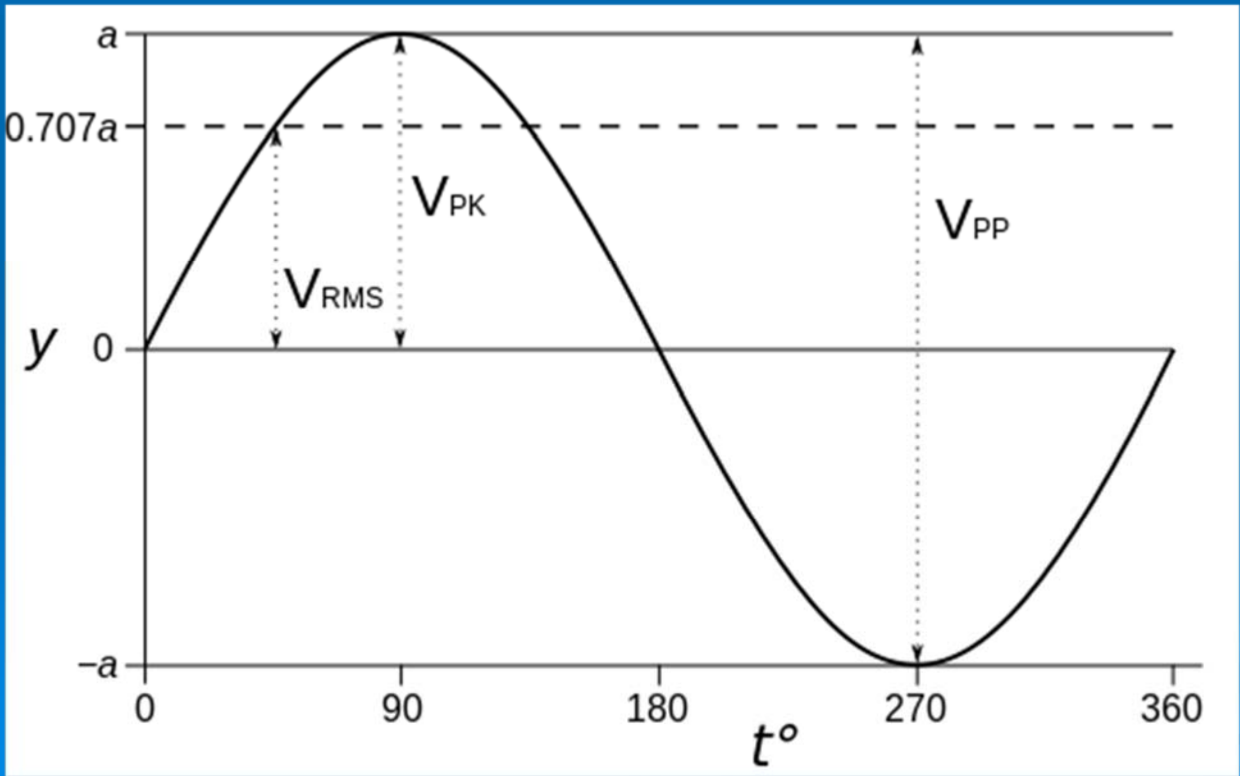
In DC, you measure *mean* value, and that's just DC value.

Mean value of alternating sine wave is 0, because it's symmetrical, goes into + and -, so in average you get 0.

For AC, *root mean square* (RMS) is used, integral of squared function measured...

AC values

For sine wave with 1 V amplitude, RMS is 0.707 V, or $\frac{Amplitude}{\sqrt{2}}$



AC values

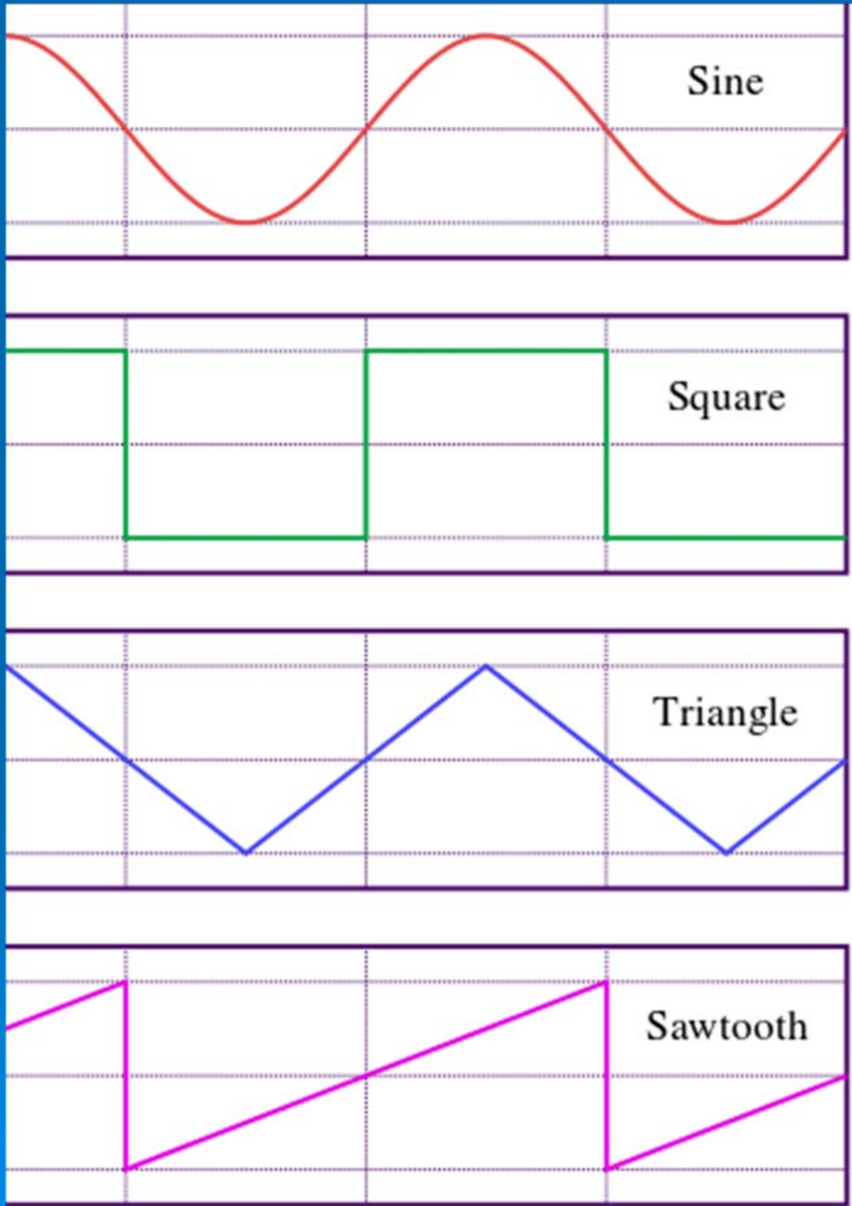
So, at AC ranges, you get RMS reading, not signal amplitude.

But, most meters are set to measure only sine wave AC vaues correctly.

RMS is dependent on wave shape, and formula changes.

Simple RMS meters don’t know what waveshape you are measuring, they assume it’s sine wave, and calculate it the same way.

AC values



Sin amplitude = 1.000 V
real RMS = 0.707 V
measured RMS = 0.707 V

Sqr amplitude = 1.000 V
real RMS = 1.000 V
measured RMS = 1.111 V

Tri amplitude = 1.000 V
real RMS = 0.577 V
measured RMS = 0.555 V

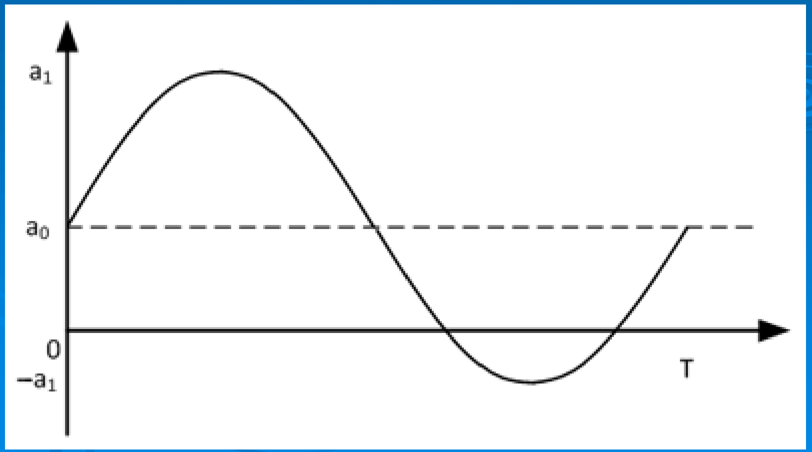
Saw amplitude = 1.000 V
real RMS = 0.577 V
measured RMS = 0.555 V

AC values

Only more expensive multimeters with TRUE RMS option measure correctly any AC waveshape.

Also, if there is DC voltage added to AC, most meters without true RMS will make errors.

That's AC+DC mode.



Measuring ACV

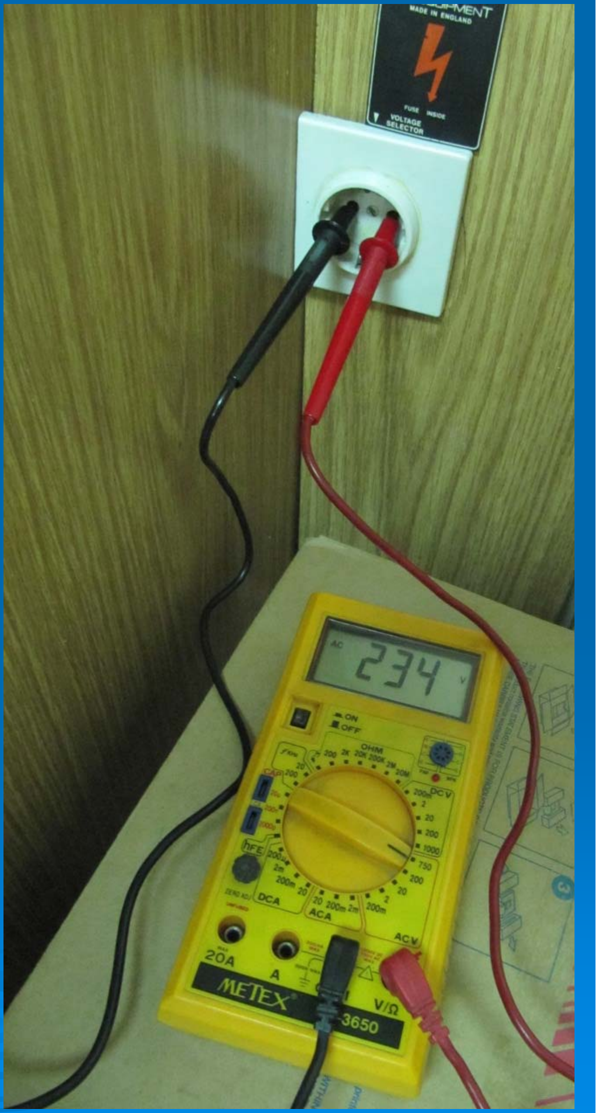
Same as DCV, just use ACV ranges.

Black probe still to GND point.

Max AC voltage safe to measure with this DMM is 750 V! Be careful!

Measuring ACV

Measuring AC mains 230 VAC!



Measuring ACA

Same as DCA, just use ACA ranges.

Be careful!

Measuring Continuity

Measuring „short circuits".

In essence, this is resistance measurement, with beep sound when measured resistance is „almost" 0 ohms.

Depending on multimeter, beep is sounded for measurements below 10-50 ohms, so it's not always really „0" ohms.

Measuring Continuity

Eg.

If there is a small transformer connected across a transistor’s output in PC PSU, measuring continuity will show transistor shorted, possibly burnt out.

But transformer’s primary winding has low resistance, around 10 ohms, and all is OK, it’s meant to work that way, but you’ll get false idea that it’s wrong. Don’t assume without thinking!

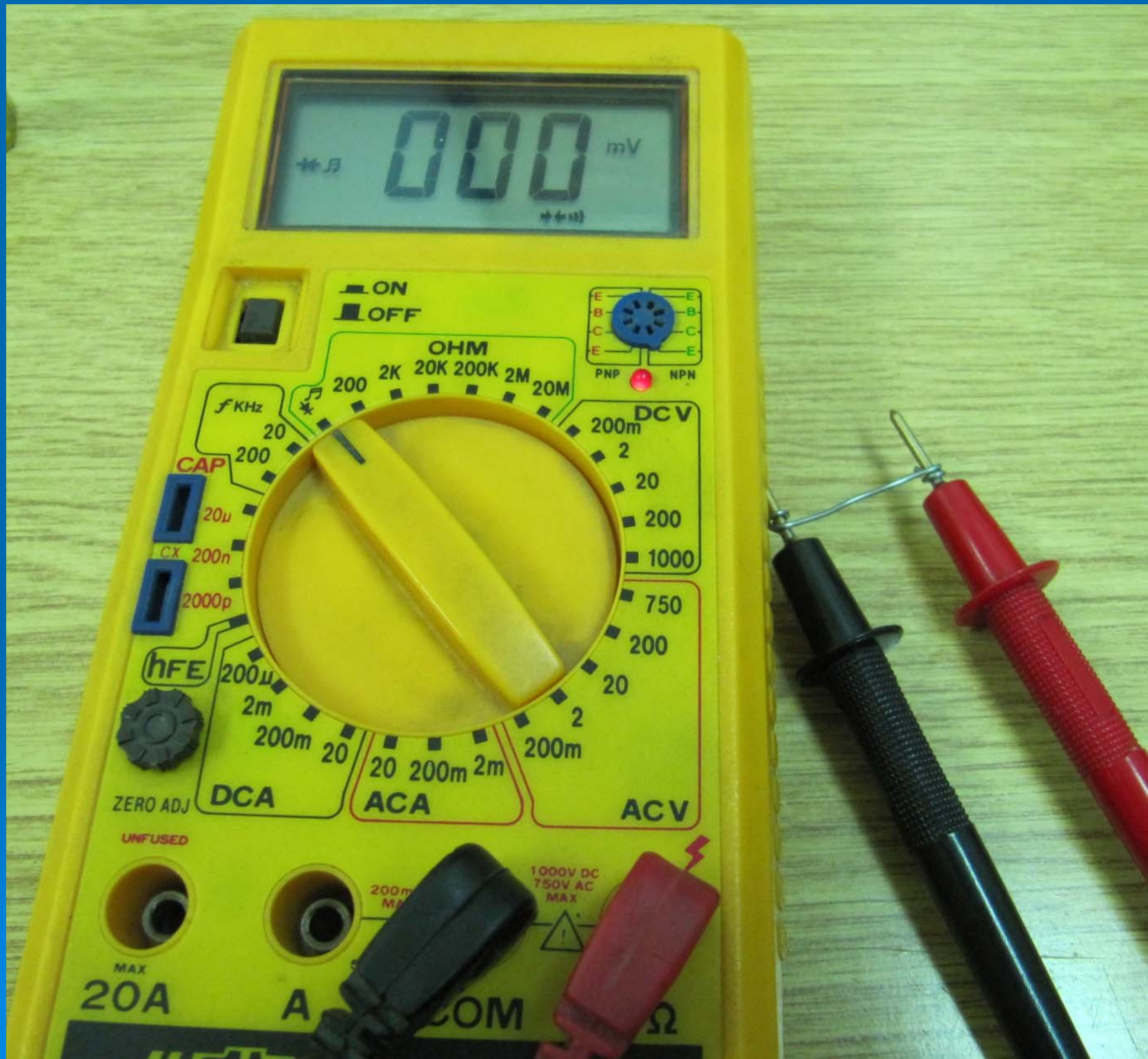
Measuring Continuity

Measurement setup - same as for the Resistance, just range switched to beep ♫.

Short the probes to check if it works.

Most importantly, <u>SWITCH OFF</u> the POWER to the circuit you are measuring!

Measuring Continuity



Measuring Diodes

Diodes pass current only in one direction, when polarised correctly.

Multimeter measures voltage drop across diode in mV.

You can test diodes:

Silicon (0.5-0.7 V drop)

Germanium (0.2-0.3 V drop)

Schottky (0.1-0.4 V drop)

Measuring Diodes

Some LED diodes with voltage drop 1.6-2.0 V, could be tested on some multimeters, if used with a resistor in series.

LEDs with larger drops can only be tested with meters that have specialised LED testing mode.

Zener diodes can't be tested in this way.

Measuring Diodes

Red probe must be in V/Ω jack, range switched to Diode. Some meters have separate Diode test range, some share the same range with Continuity tester.

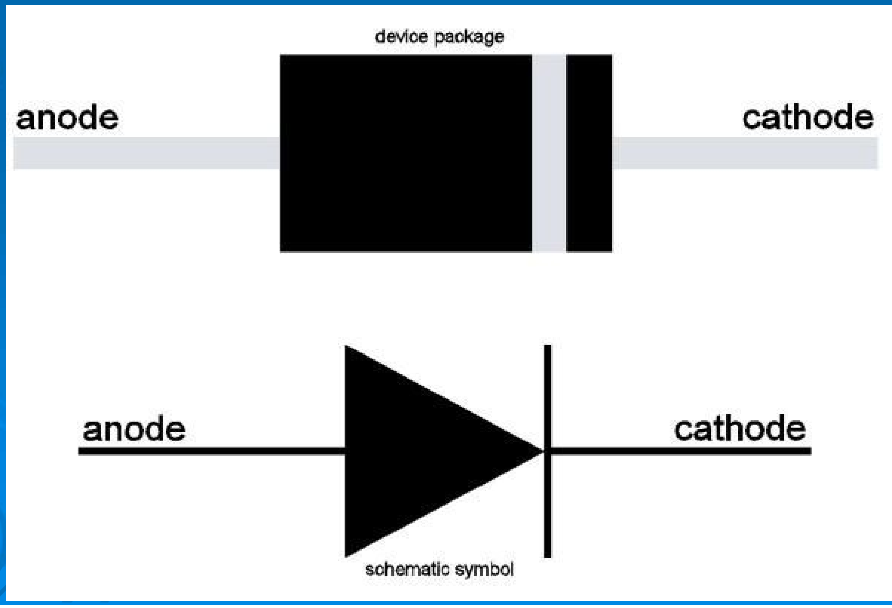
Measuring Diodes

Measure only free, separate diodes, without any power applied.

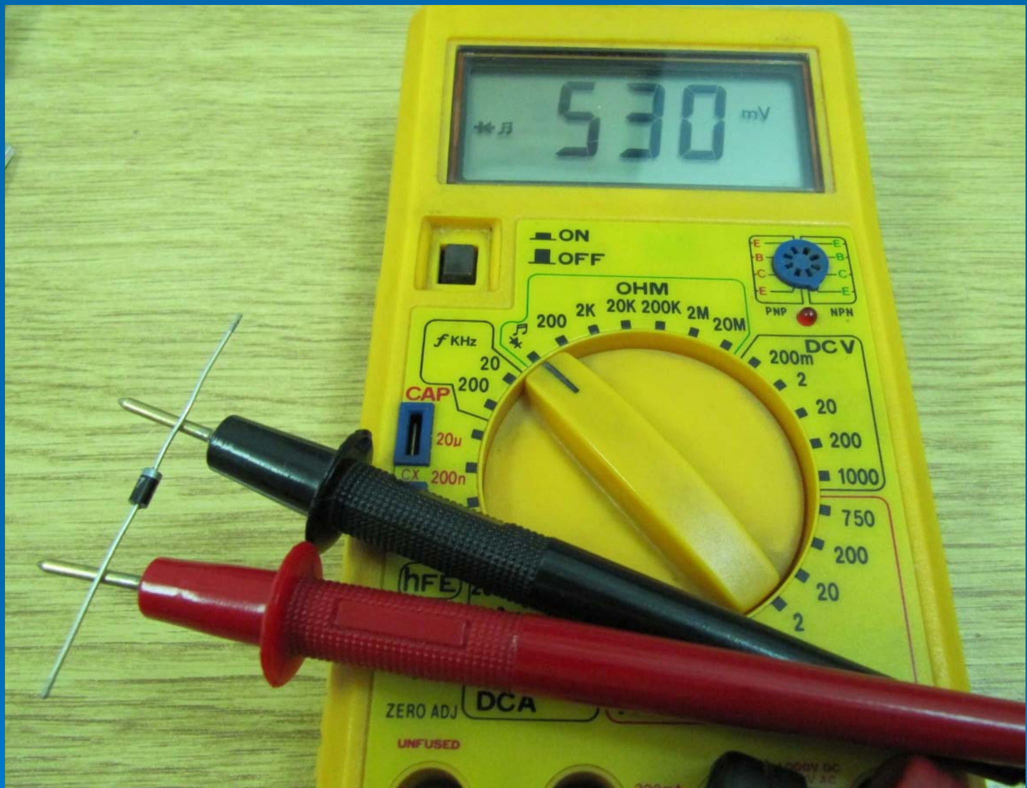
Connect red probe to diode’s anode, and black to cathode.

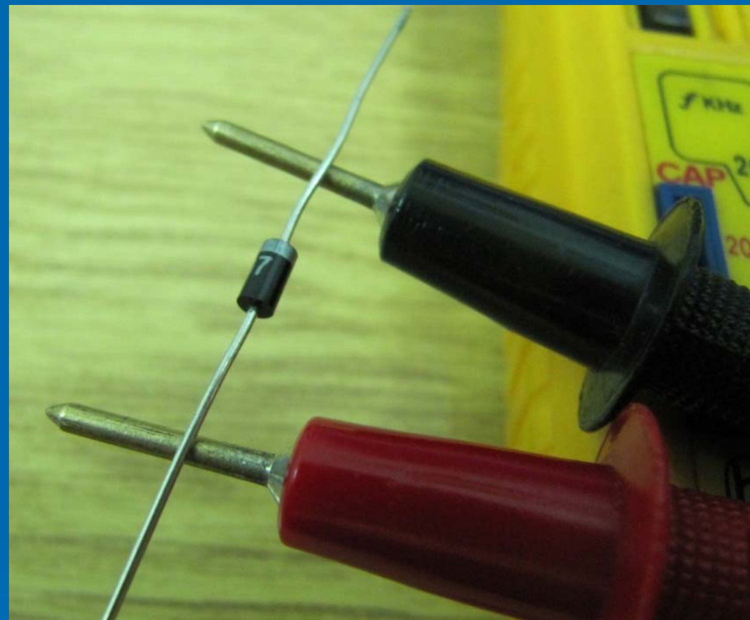
Diode should be in „on“ state – conducting.

Meter shows diode voltage drop in mV.



Measuring Diodes





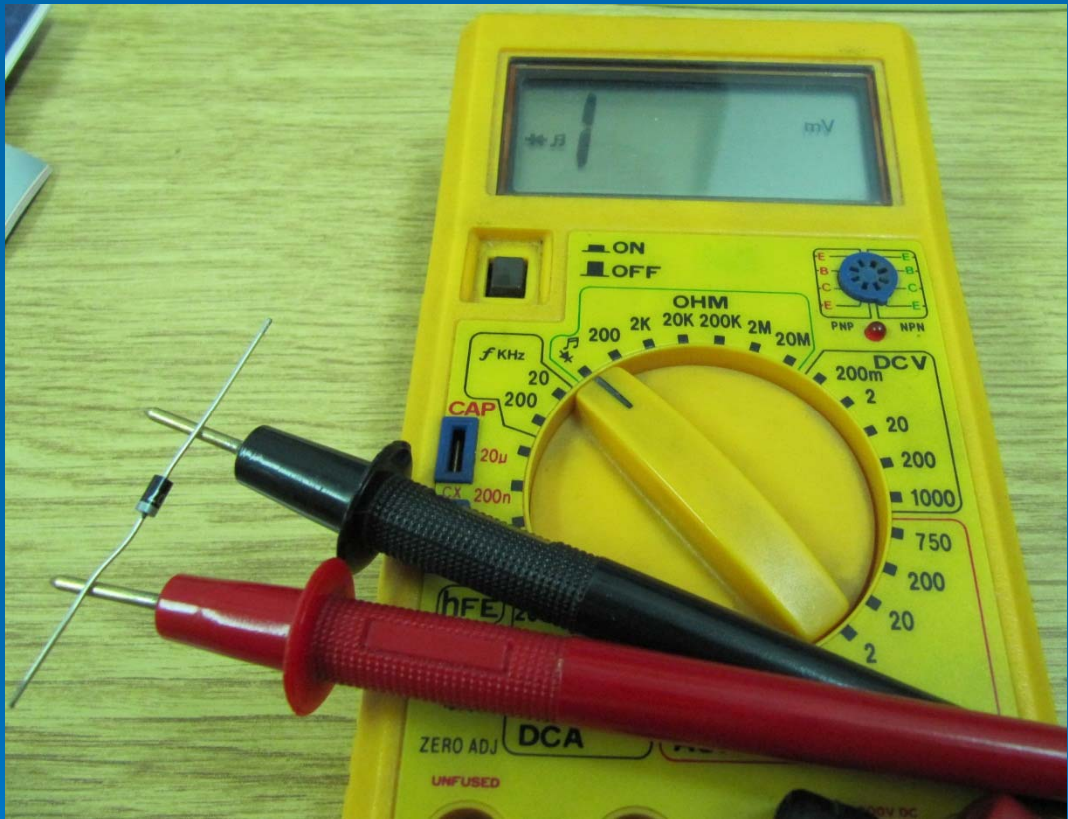
Measuring Diodes

Now connect black probe to diode’s anode, and red to cathode.

Diode should be in „off“ state, and meter will show „1“ ie. overrange, meaning there is full test voltage across the diode.

If some value is displayed, or 0 read in both tests, diode is broken.

Measuring Diodes



Measuring Transistors

You can check bipolar NPN and PNP transistors in the same way. FET, MOSFET and other types of transistors must be tested in a different way.

Transistor can be simplified and represented as two connected diodes. You test both diodes, and if both are OK, transistor *should* be OK also in most cases.

Determine emitter, base and collector pinout using transistor datasheet, or just test it.

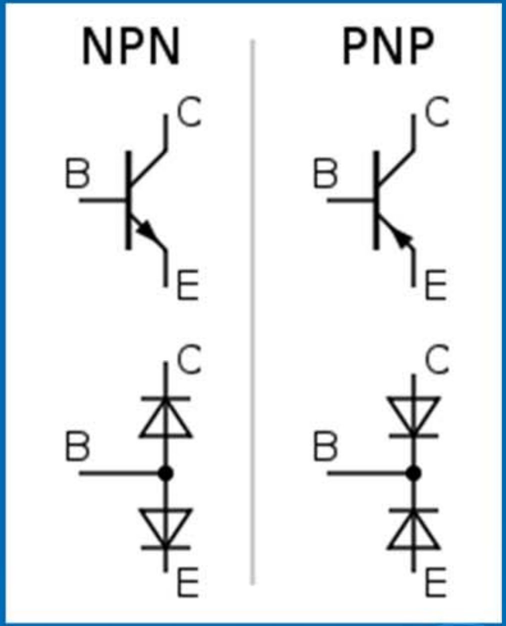
Measuring Transistors

All tests must be OK for NPN:

Red to B, black to C or E – on

Black to B, red to C or E – off

Red to C or E, black to E or C - off



All tests must be OK for PNP:

Black to B, red to C or E – on

Red to B, black to C or E – off

Red to C or E, black to E or C - off

Measuring Transistor hFE

hFE, or β, is transistor gain.

If you don't know what it's for, you don't need it.

Procedure is simple:

Disconnect both probes. Switch into hFE range. If you know transistor E/B/C pinout and polarity, put it into correct slot. If not, keep trying until it shows some value.

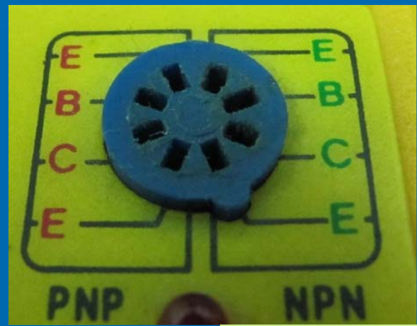
Measuring Transistor hFE

All hFE readings in 150-800 range mean that transistor is OK.

Important for analog electronics, and matching transistors for similar perfomances.

Considered as „gimmick“ in cheaper multimeters. Not that useful most of the time.

Measuring Transistor hFE



Measuring Frequency

Measuring relatively low frequencies of simple signals. For high frequencies and more complex signals, oscilloscopes and signal analyzers must be used.

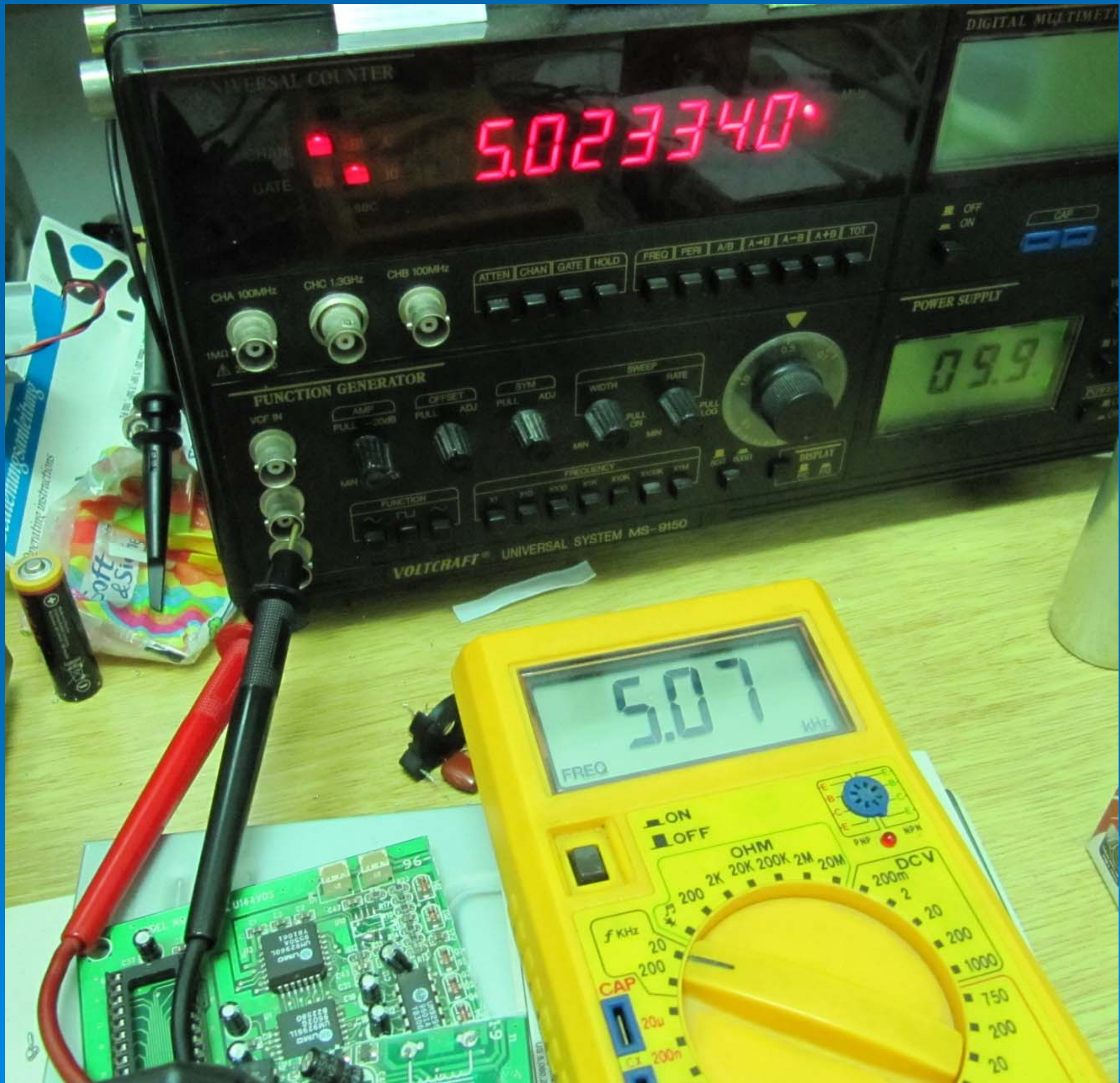
Check multimeter datasheet for minimal and maximal amplitudes of signals that can be measured. If singal is too low, you can't measure it's frequency. Too high signals may cause errors or damage the meter.

Measuring Frequency

Red probe to V/Ω input. Range switch to *f* range. Displayed values are in kHz. Some mulitmeters have ranges up to 2 MHz, this one only to 20 kHz (audio range).

Black probe to GND, red to signal.

Measuring Frequency



Measuring Capacitance

For precise C measurements, LCR meters are used. This meter only measures smaller value non-polar capacitors, not suitable for larger and electrolytic capacitors.

Ranges 2000 p, displays value in pF, 200 n in nF, and 20 μ in μF.

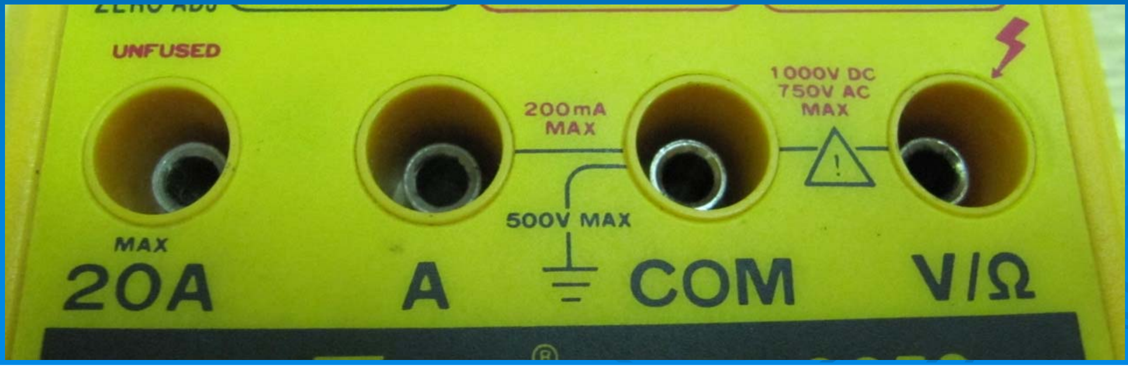
The larger the value, longer the time for measurement is needed. This type of measurement has relatively large errors, 2-10%.

Measuring Capacitance

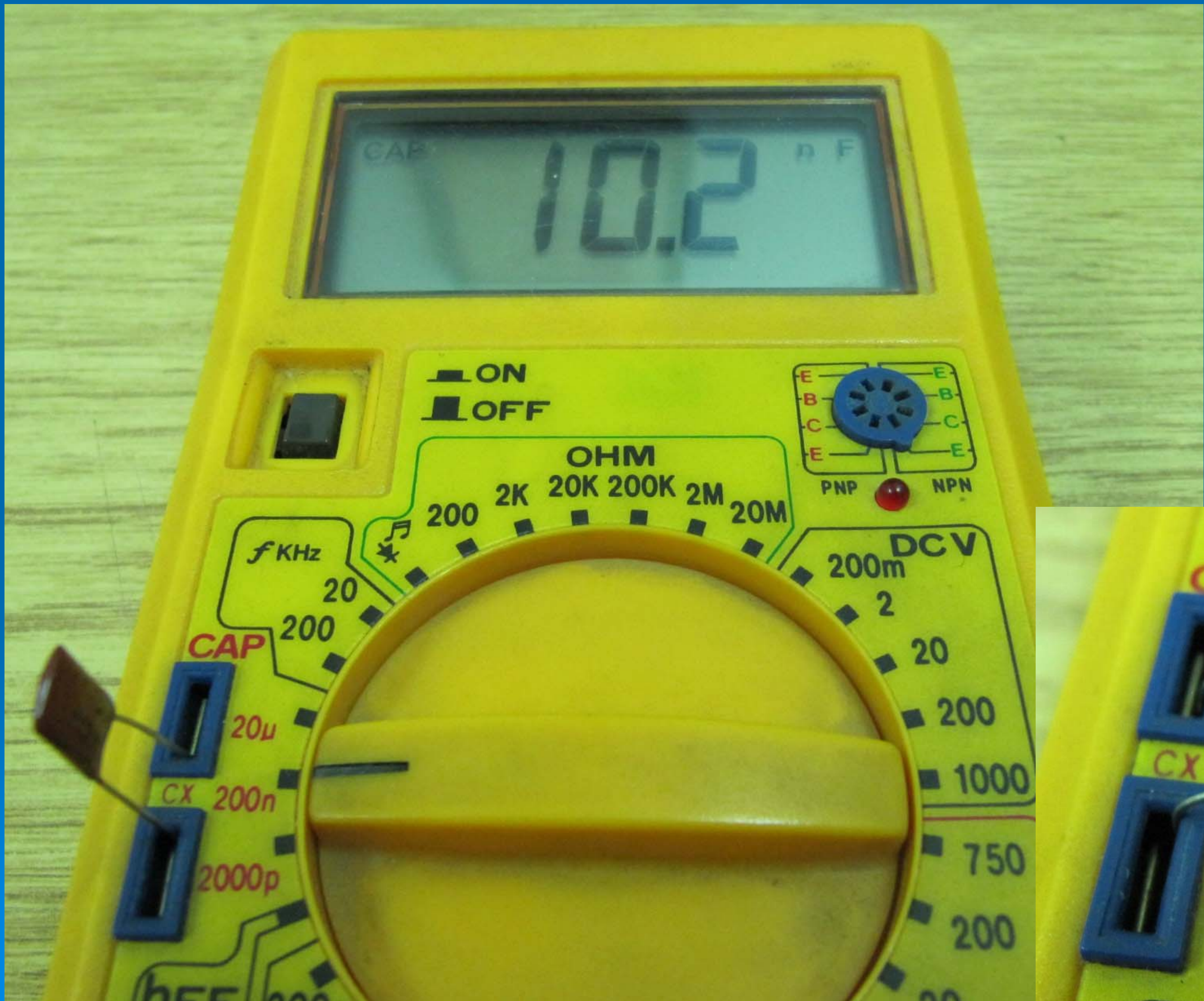
Only free capacitors can be measured. No capacitors mounted in a circuit can be easily measured.

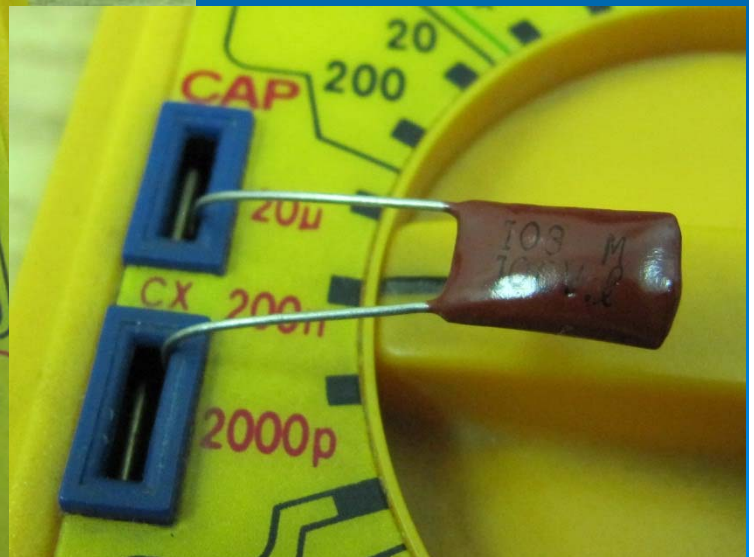
Disconnect probes. Switch range to largest one. Connect capacitor terminals to Cx connector.

Switch to smaller range if needed.



Measuring Capacitance





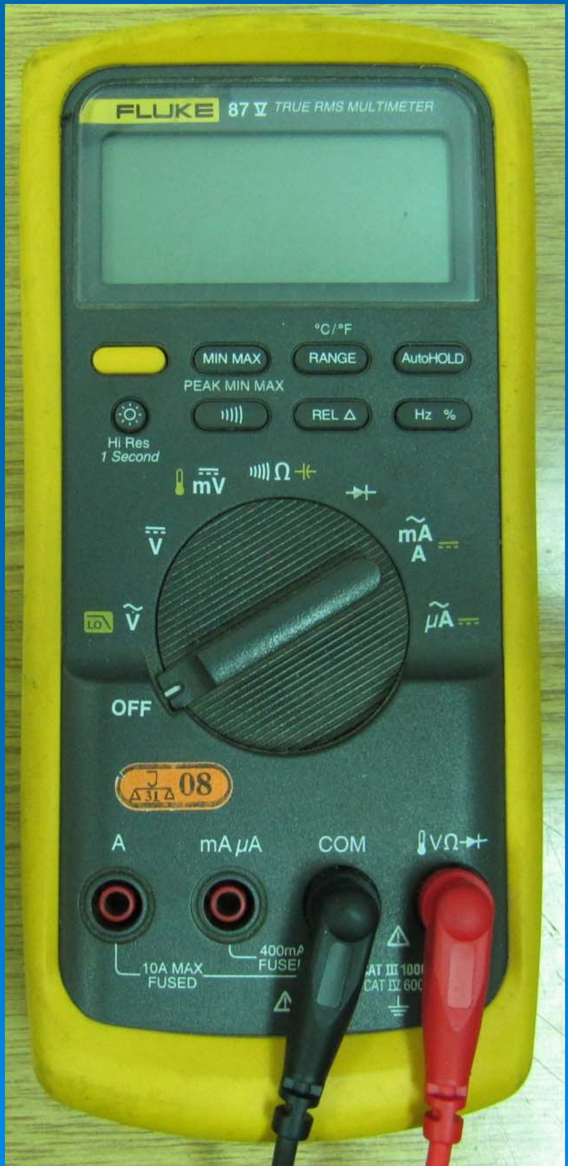
Autoranging DMM

Simpler to use, no range switching. Multimeter logic switches to the most appropriate range.

Just select range function to be measured, and the rest of the procedure is the same.

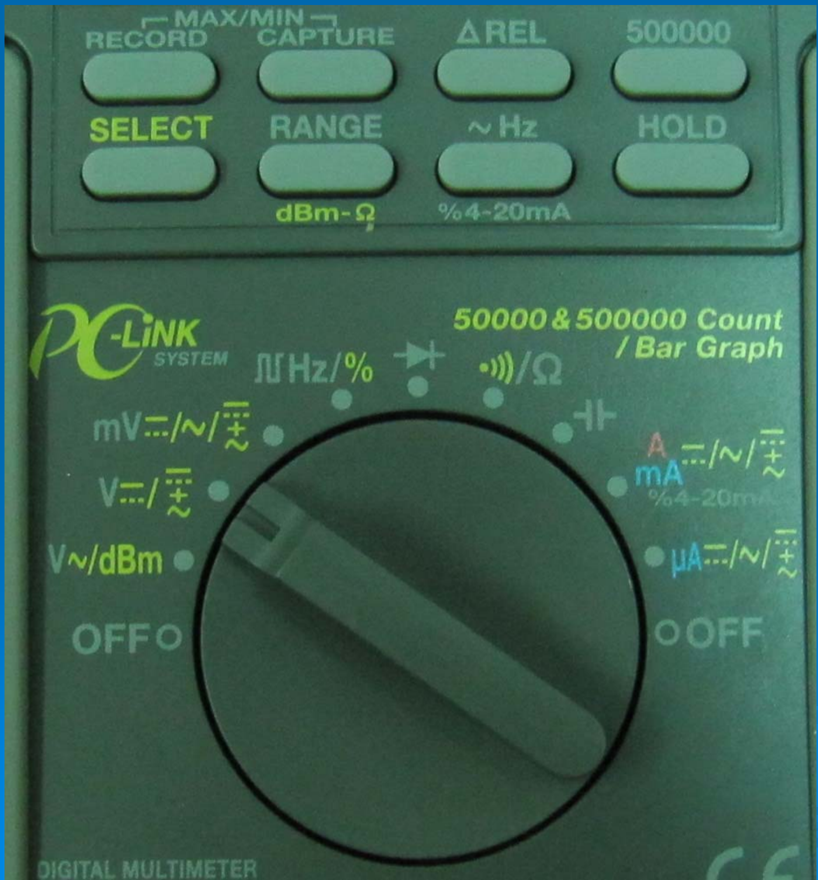
On some models you can override autoranging, and select range manually via function buttons.

Autoranging DMM

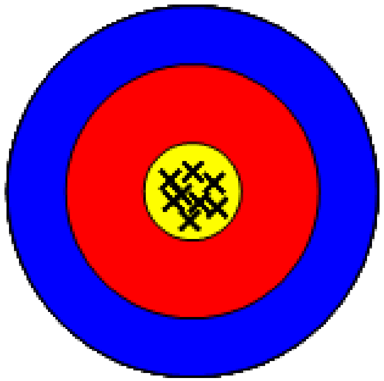
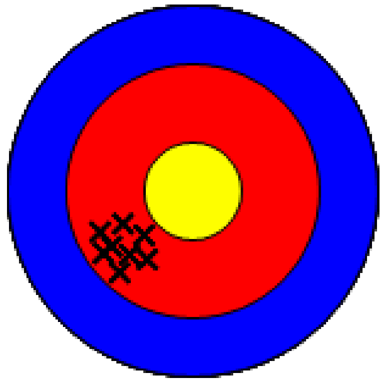
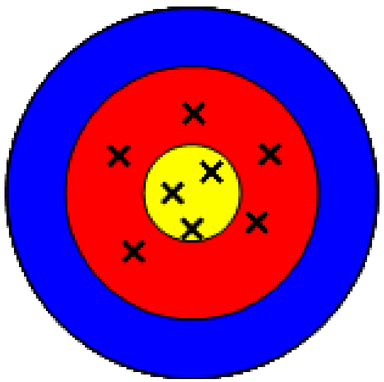
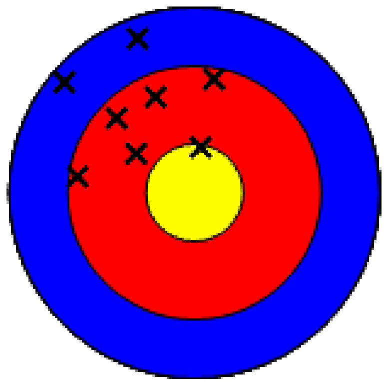


Autoranging DMM

More expensive meters, have many more functions and features...



Accuracy and Precision

	Accurate	Inaccurate (systematic error)
Precise		
Imprecise (reproducibility error)		

Accuracy

Often given as:

A % of reading for B range + C digits

DMM we used here has 0.3% + 2 digits accuracy for all DCV ranges.

So, when measuring 15.00 V at 20 DCV range, maximal error is 0.3% * 15 V = 45 mV + 1 last digit at 20.00 V range, it’s 1*0.01 V = 10 mV. In total, error is 45+10 = 55 mV

Accuracy

So the real value of the measured voltage is anywhere in the range of 15 V +/- 55 mV,

or in the range 14.945 – 15.055 V.

If we measure the same voltage at 200 V range, max error is 45 mV + 1*0.1V = 145 mV.

That's why you always need to measure at the right range, if the value is near the lower end of scale, you get large errors. Find the right range just above the measured value.

Accuracy

Two multimeters can have same resolution (number of digits), but the more expensive ona has smaller accuracy error...

4 ½ digits, 19999 counts, 2 V range, displays 1.9999 V, 0.1 mV resolution.

For accuracy 0.5% at 2 V range = 10 mV,

so the last two decimal digits are useless!

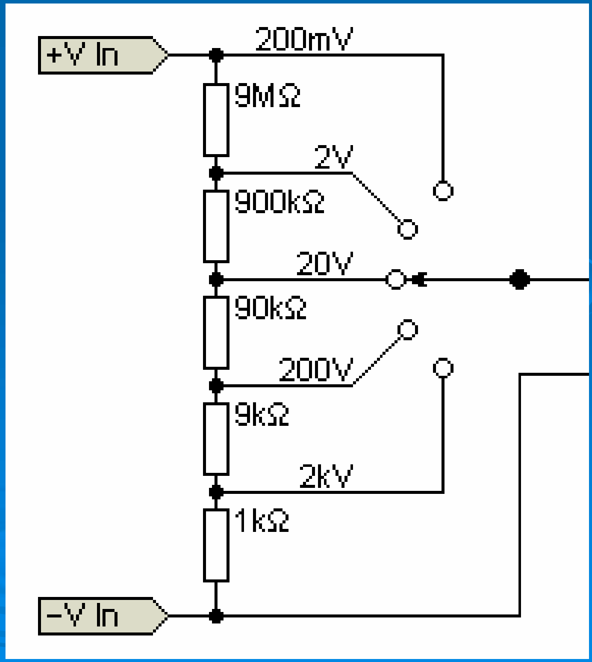
You get 0.1 mV resolution, but accuracy is 100x worse, so it's waisted investment...

Accuracy

DMM at the core is single range digital DC voltmeter, in this case 200 mV DC.

All higher voltages are scaled down with input resistor dividers to 200 mV.

2 V range scales 10x down, 20 V 100x, 200 V 1000x, and 1000 (2000) V 10000x down, all to 200 mV.



DMM

That's why DC range is the most accurate.

ACV must be scaled down and transformed to DCV to be measured, and more errors are introduced in the process.

Current must be scaled down, passed thru known reference resistor Rs, for AC must be converted into DC also, and then voltage is measured across the resistor.

Meter displays current calculted as Ix = Umeasured/Rs.

Eg. 20ACA error is larger: 3.0% + 7 digits.

DMM

Sum of all resistances in resistor divider network, makes total input impedance of the multimeter. Higher the value, smaller the error due to the input loading.

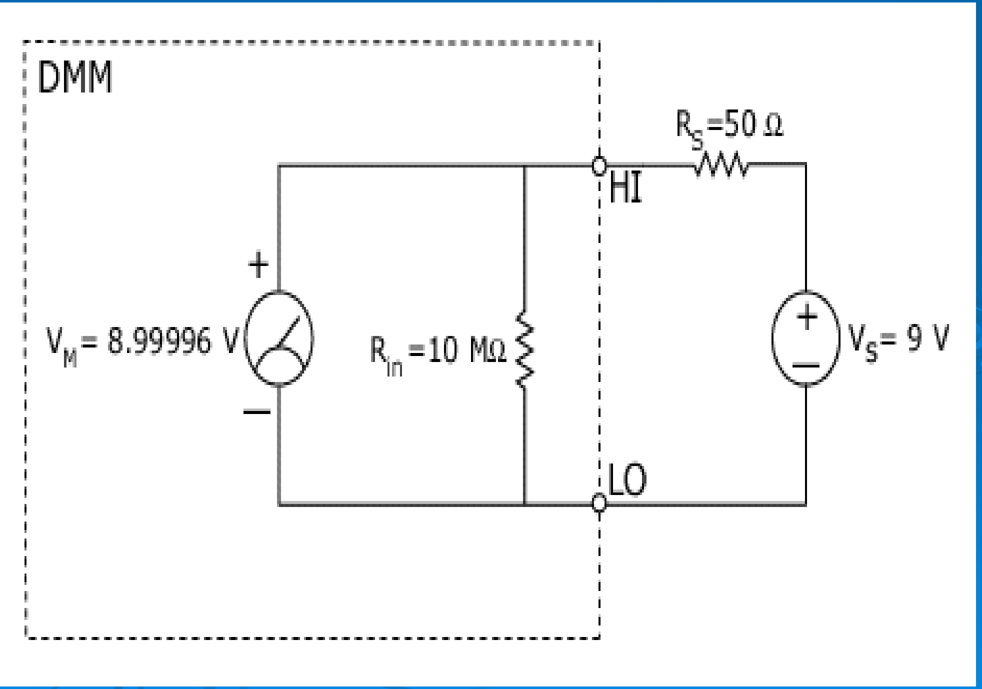
Typical DMM input resistance is 10 MΩ and more, for better DMMs.

Cheaper DMMs have values around 1 MΩ.

DMM

DMM input resistance and source output resistance form a voltage divider, and introduce error due so the loss at Rs, so measured voltage is smaller than original.

For very large Rin, error is negligible.



Safety

Cheap DMMs have poor safety, small glass fuses, no overload or short circuit protection.

Test probes (leads) are poor quality, prone to breaking, whole meter is badly assembled with low quality parts, plastic case easily damaged, low accuracy, short working life, easily broken, unreliable readings and functions.

Still, most can be used for low power non-precision home electronics.

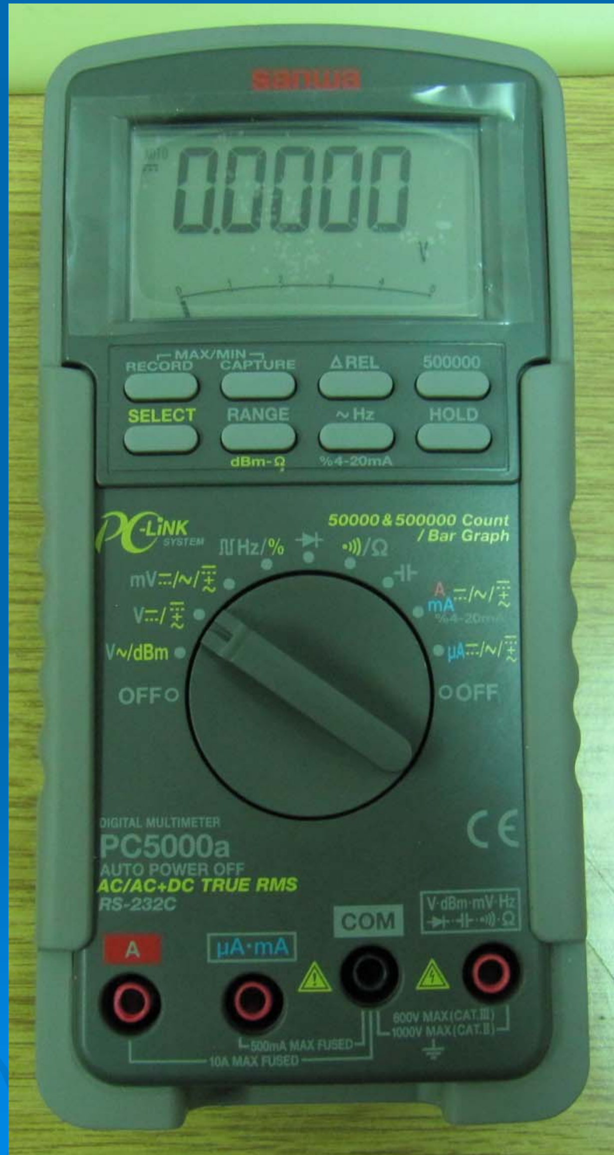
Be careful when measuring AC mains...

Cheap DMMs


DCV
ACV
DCA
OFF
10A DCA
hFE
NPN
PNP
10ADC
VΩmA
COM
DT-830B
DIGITAL
MULTIMETER


DIGITAL MULTIMETER
FUKE
DT9205
20A
mA
COM
VΩ

Quality DMMs



Analog Multimeters (AMM)

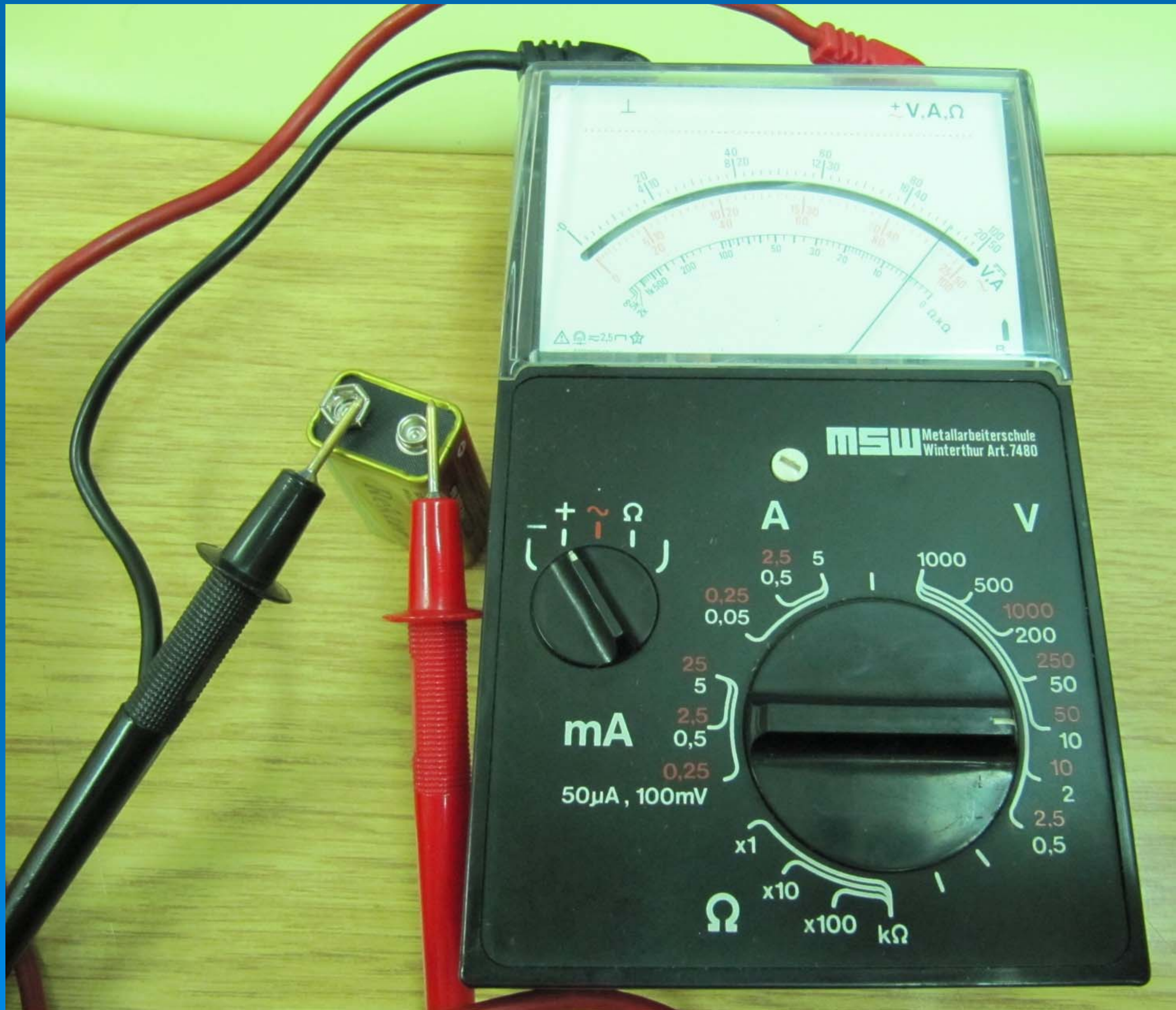
Older, less accurate, less functions.

Reading is from a scale with a pointer.

Input resistance is much smaller than in DMMs, and changes with each range.

Being electro-mechanical device, it’s prone to mechanical stress damage.

Analog Multimeters (AMM)



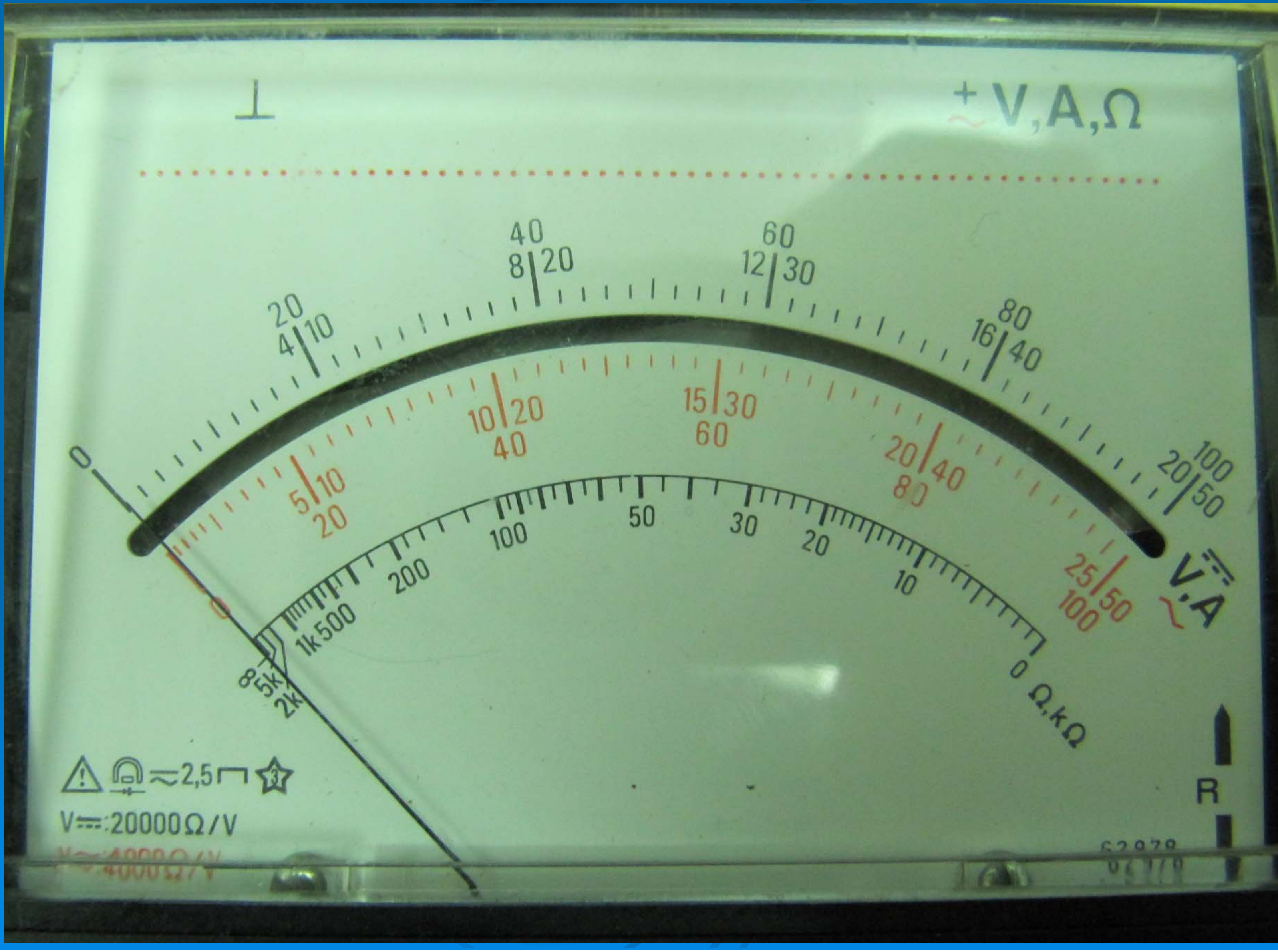
Reading Analog Scale

Some AMM use single scale for all V and I mesurements, other separate for every function, even range.

If scale has 100 tick marks, and range is 50 V, then last tick marks 50 V, and each tick is 0.5 V. Changed to 200 V range, maximum becomes now 200 V, and each tick has 2 V value.

Scale with 60 ticks, at range 3 mA, max is at 60 ticks, each is 50 uA; at range 6 mA ticks are 0.1 mA; at range 180 mA ticks are 3 mA.

Reading Analog Scale



Reading Analog Scale

Some or all AC ranges have separate scales. Resistance scale always has separate, inverted scale. That’s because AMM at the core is a ampermeter, and for 0 current needele is full left, meaning resistance is almost infinite.

For max current resistance is 0, needele on the far right. Here you must set 0 ohm reading. Connect probes together, set 0 ohm dial so pointer shows 0 mark exactly.

Reading Analog Scale

Some AMM have mirror in the scale. It's called antiparallax mirror, for eliminating error due the readout when looking at the pointer from the different angles.

Position yourself directly above scale, look down, close one eye, and move your head until you see that pointer overlaps with it's reflection in the mirror. This is the right angle of observation, and pointer points to the right mark.

AMM Advantages

Less electronic parts, less chance for breakdown, long lasting if made in quality production.

Lower input resistance eliminates „ghost“ readings due parasitic induction in power lines.

Pointer needle movement makes good tracking indication of slow changing values
(bar-graph tries to replace it in DMMs).

AMM Advantages

Most of the AMMs are passive type, using miniscule current from measured signal to move the pointer, so no batteries needed!

No batteries, no leakeges!

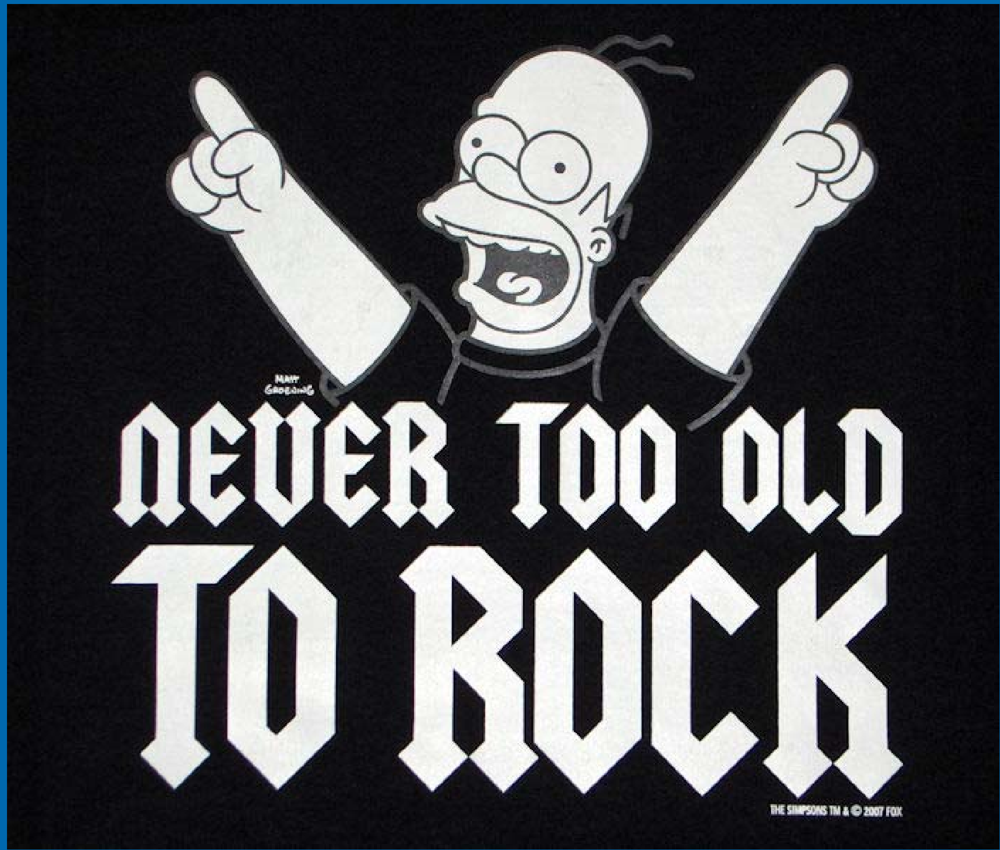
AMM Advantages

Voltage and current can be measured in passive way, but for resistance, battery is needed for constant current source, also for diode test, but anode/cathode logic is reversed to DMM case.

Still, AMMs look cool! ☺

If properly calibrated, AMM is more than enough for small everyday electronics.

Almost Done...



HOORAY, IT'S OVER!

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