Hands-on training of cryogenics

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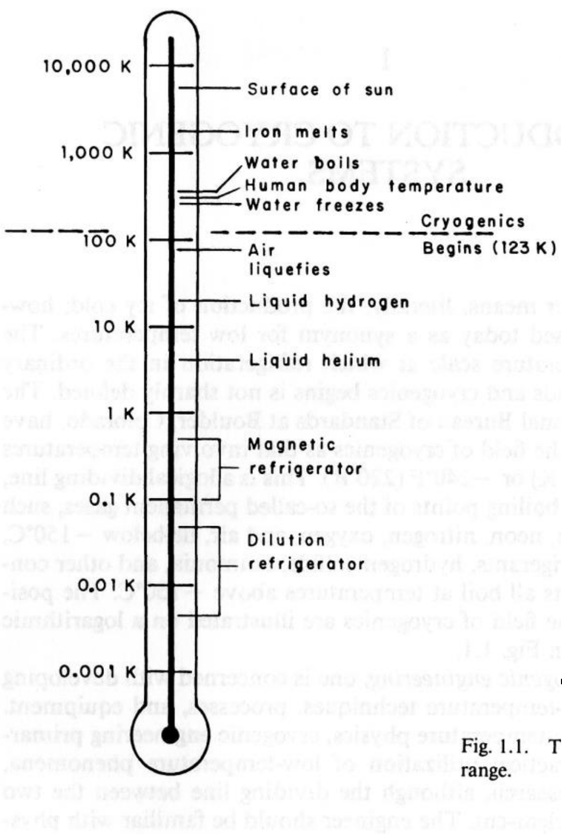
Cryogenics

- Cryogenics : Cryogenics is a branch of physics that studies what happens to things at low temperatures.
- The cryogenic temperature range is below 123K (~ -150℃)



Ref. Collins COBUILD Advanced Learner's English Dictionary)

How to handle "the cold"

- Liquid nitrogen is EXTREMELY cold, and should only be used by trained professionals.
- Proper safety techniques should always be followed, including the use of splash goggles and thermal gloves.

- Closed container with a loose fitting top

that allows venting

- Use only vessels approved to contain $L.N_2$
- $L.N_2$ must be transported and stored in an appropriate container containing pressure relief devices.

Hands-on training items

1. Liquid Oxygen
2. Eddy current
3. Cryogenic temperature

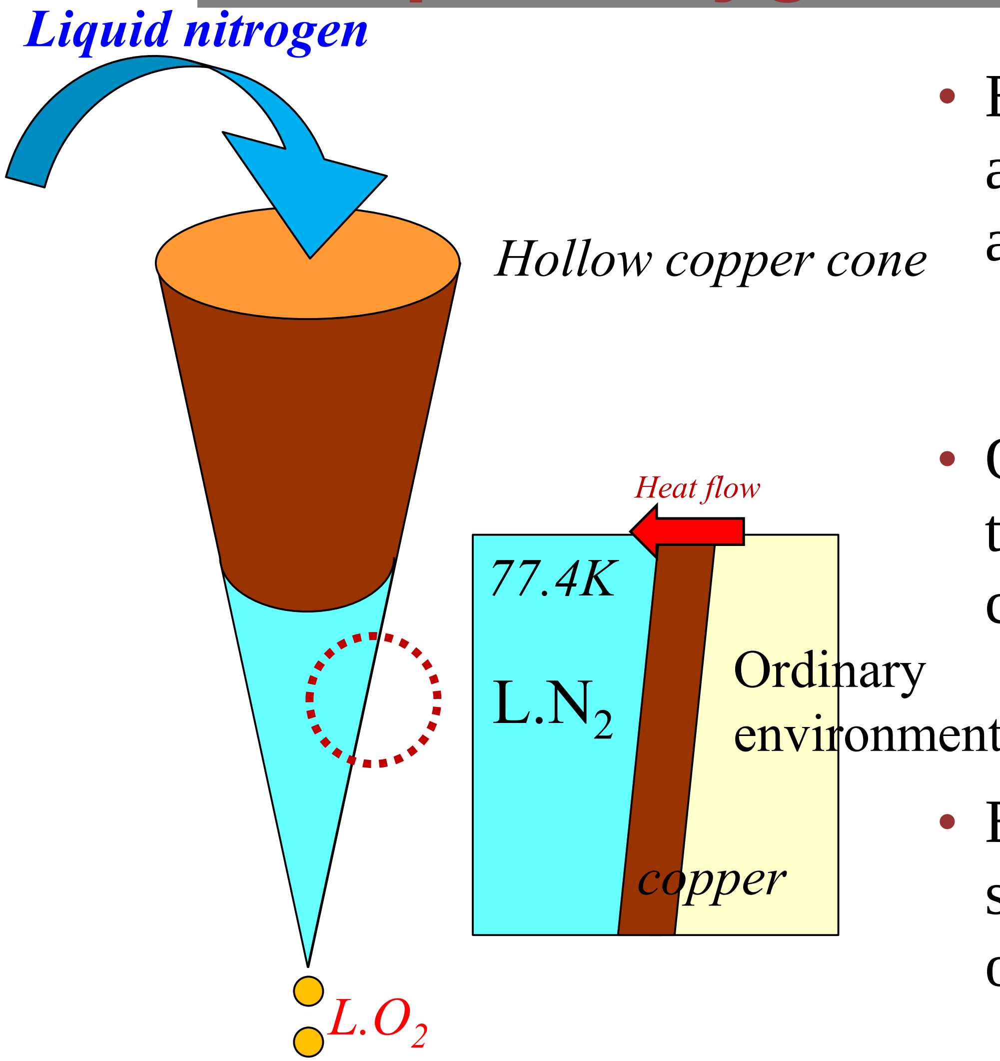
1. Liquid Oxygen

- Composition of dry air

Element	Ratio in vol (%)	Boiling point (K)
Nitrogen, N_2	78.084	77.4
Oxygen, O_2	20.946	90.2
Argon, Ar	0.9340	87.3
Carbon dioxide, CO_2	0.04	194.7

- If Air faces a liquid nitrogen ...
- Liquid nitrogen will boil at a temperature of -195.8°C (77K) which is lower than the boiling point of oxygen, argon and carbon dioxide.
- Since nitrogen's boiling point is a lower temperature than oxygen's boiling/condensation point, oxygen gas from the air will condense to a liquid at this temperature.

1. Liquid Oxygen



- Begin by pouring a decent amount of liquid nitrogen into a hollow copper cone.
- Oxygen will condense on the thermally conductive copper cone, and run down the cone.
- By elevating the cone, we can see liquid oxygen dropping off of it.

1. Liquid Oxygen

- Oxygen is paramagnetic, which means it is weakly attracted to a magnetic field.
- Using a strong enough magnet, we can confirm that this is liquid oxygen we're observing.
- To collect a sample of liquid oxygen, place a big Styrofoam box of liquid nitrogen under your dripping liquid oxygen.
- Secure a small Styrofoam cup under the falling oxygen, and then adjust the position of the copper cone so the oxygen will be collected in the Styrofoam cup.
- If pale blue liquid O_2 is seen, remove LN_2 traps (if any), flammables, and any ignition sources and let O_2 boil off slowly.

2. Eddy current

- If we have a magnet, and we move it through the air, nothing happens. But if you move this magnet over an aluminum plate, we move the aluminum plate without touching it. And this is already due to eddy currents.
- If we induct eddy currents with our magnetic field, the eddy currents create a counter magnetic field and this field wordks against our movement.
- Some material is really hard to move. it depends on electrical conductivity. Low electrical conductivity material is not easy to move.

2. Eddy current

Maxwell equation (in vacuum)

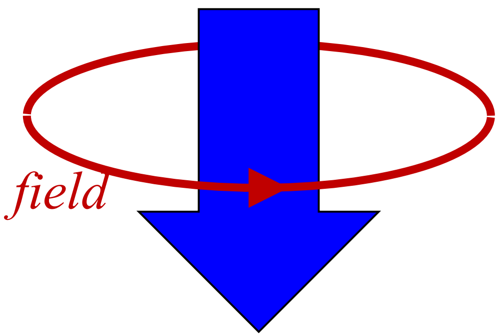
$$\nabla \cdot E = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot B = 0$$

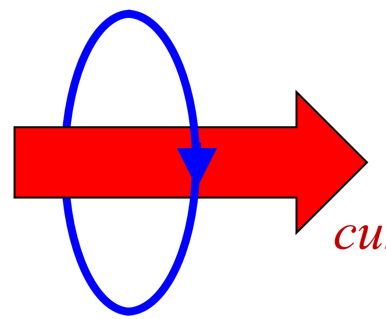
$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$c^2 \nabla \times B = \frac{j}{\varepsilon_0} + \frac{\partial E}{\partial t}$$

Varied(Increasing) B-field



Electric field



current

If the magnet is surrounded by conductors,

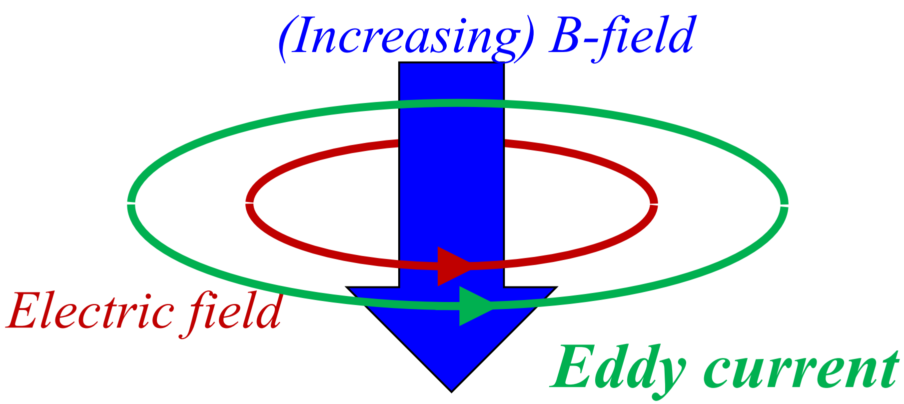
2. Eddy current

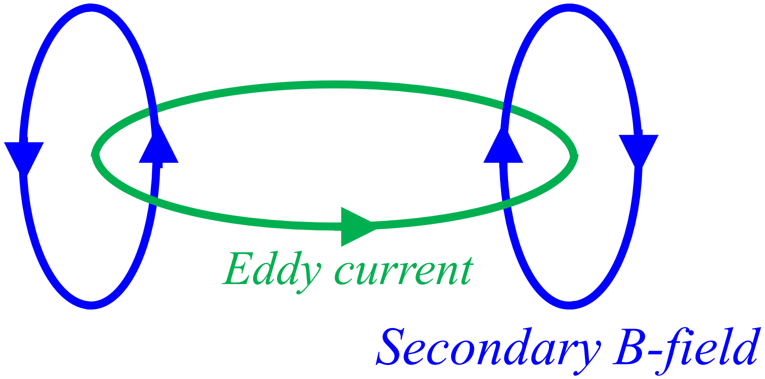
If the magnet is surrounded by conductors,

Ohm's law $j = \sigma E$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$c^2 \nabla \times B = \frac{j}{\varepsilon_0} + \frac{\partial E}{\partial t}$$

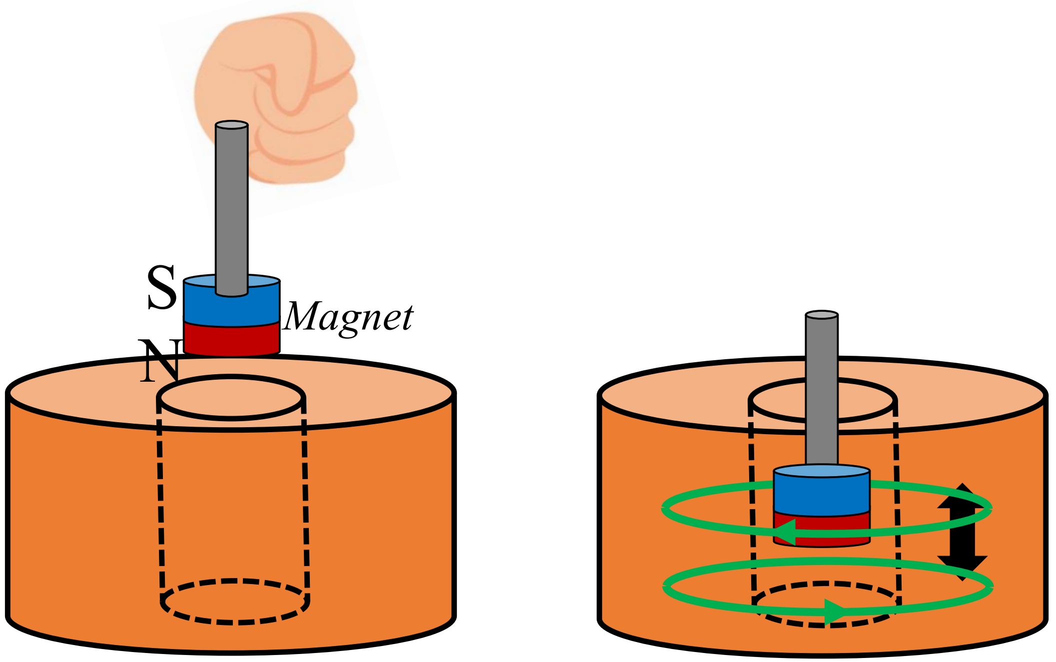




2. Eddy current

How do you feel if you shake a magnet in a conductor?

[Lenz's law]
The direction of current induced in a conductor by a changing magnetic field will be such that it will create a magnetic field that **opposes the change** that produced it.

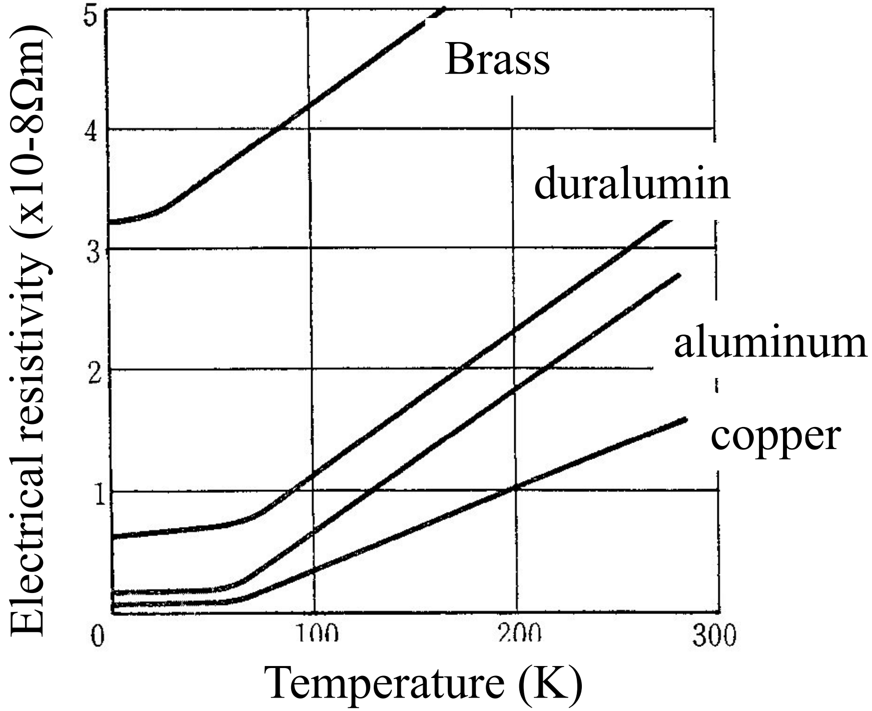


- Law of the conservation of energy

Ohmic loss due to eddy current consumes energy. Who pay it?

2. Eddy current

Material	Electrical resistivity (Ωm)	Ratio
Stainless steel (SUS304)	7.2×10^{-7}	42
Aluminum	2.7×10^{-8}	1.6
Copper	1.7×10^{-8}	1.0
Perfect conductor	0	0



Is there a perfect conductor?

Cold copper is a good conductor.

$$R = R_{ref}[1 + \alpha(T - T_{ref})]$$

R : Conductor resistance at temperature
α : Temperature coefficient of resistance for conductor material
T : Conductor temperature in degrees Celcius.

2. Eddy current

A magnet move it through the various materials (copper, aluminum, brass and cryogenic copper)

Try to feeling Eddy currents

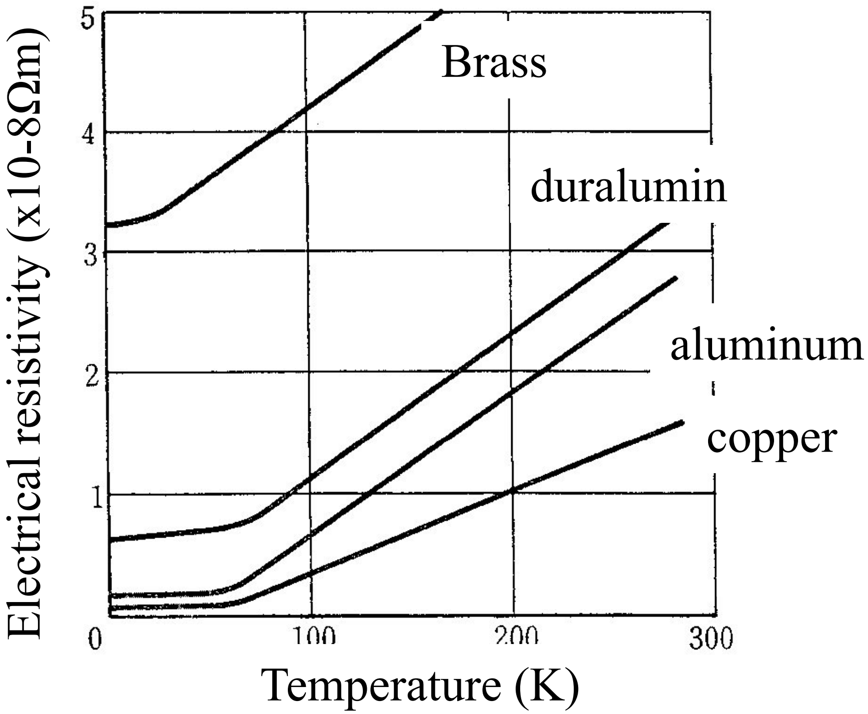
3. Cryogenic temperature

RLC is base components of electronics system.

Some devices showed a dramatic decrease of capacitance and resistivity at cryogenic temperature.

$$R(C) = R(C)_{ref}[1 + \alpha(T - T_{ref})]$$

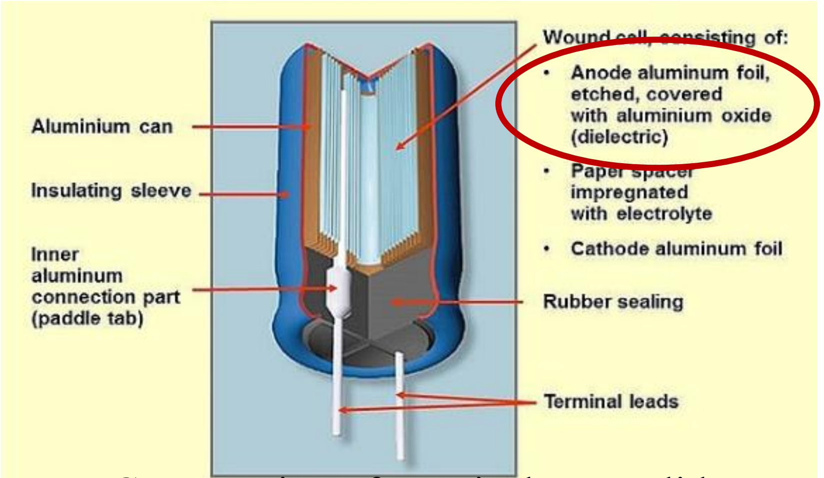
R : Conductor resistance at temperature
C : Conductor capacitance at temperature
α : Temperature coefficient of resistance and capacitance for conductor material
T : Conductor temperature in degrees Celcius.



3. Cryogenic temperature

Type : Electrolytic Capacitor, Aluminum capacitor

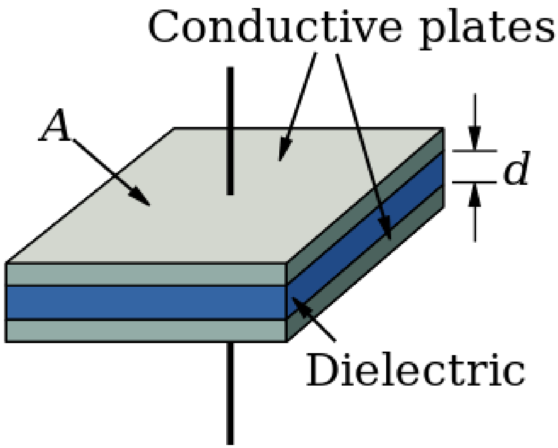
Anode	Dielectric
Aluminum	Aluminum oxide



Construction of a typical non-solid aluminum electrolytic capacitor

Changes in temperature around the capacitor affect the value of the capacitance because of changes in the dielectric properties. If the air or surrounding temperature becomes to hot or to cold the capacitance value of the capacitor may change so much as to affect the correct operation of the circuit.

3. Cryogenic temperature

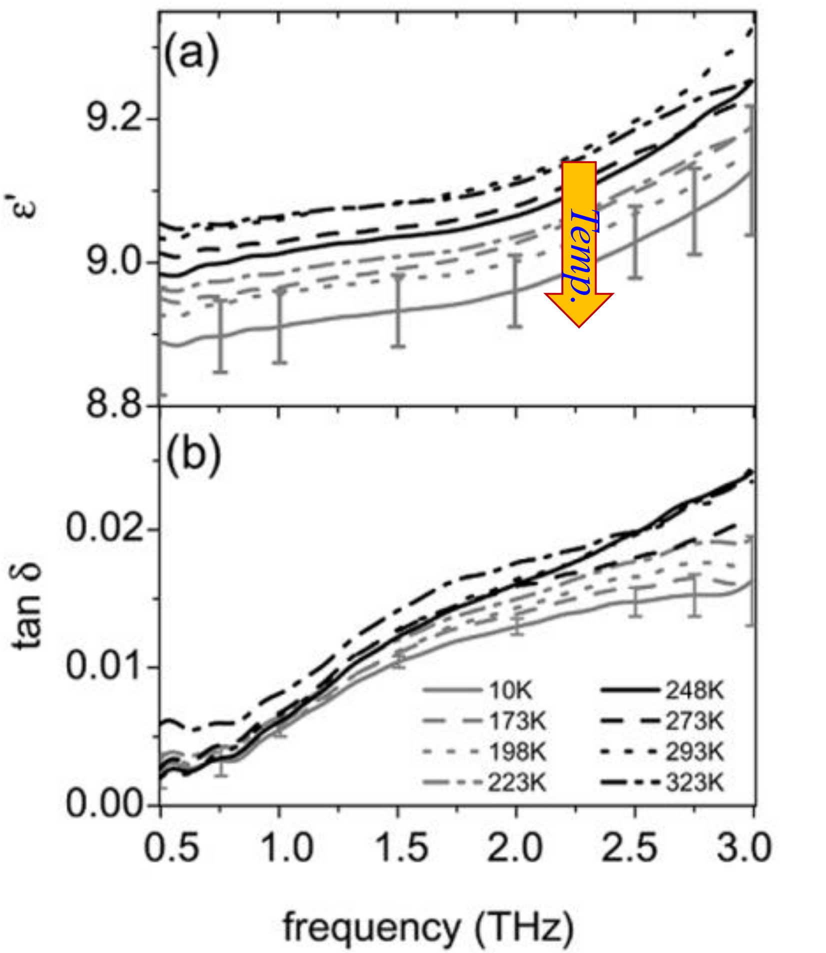


$$C = \epsilon \frac{A}{d}$$

$$C = C_{ref}[1 + \alpha(T - T_{ref})]$$

C : conductor capacitance of material at temperature
α : Temperature coefficient of capacitance for conductor material
T : Conductor temperature in degrees Celcius.

The temperature coefficient of the material is positive.



(a) Permittivity and (b) loss tangent versus the frequency of **alumina** given at different temperatures.

3. Cryogenic temperature

In my case,

C_{ref} =2.4 uF

T_{ref} = 20 °C

T = -195.8 °C

C = 0.298 uF

→ $\alpha_{(capacitor)} = 4.07 \times 10^{-3}$ / °C

Select : Capacitance meas.

Range : Auto or proper

The normal working range for most capacitors is -30°C to +125°C with nominal voltage ratings given for a working temperature.

3. Cryogenic temperature

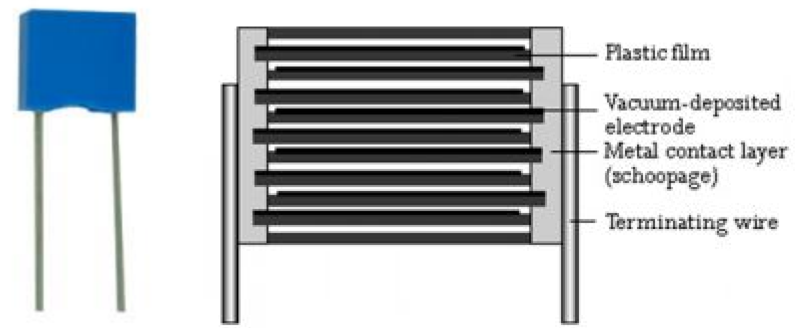
- Type : Metallized polyester film capacitor (PET)

$$C = C_{ref}[1 + \alpha(T - T_{ref})]$$

C : conductor capacitance of material at temperature
α : Temperature coefficient of capacitance for conductor material
T : Conductor temperature in degrees Celcius.

In case of PET capacitor

C_{ref} =330 nF
T_{ref} = 20 °C
T = -195.8 °C
C = 0 nF
→ $\alpha_{(capacitor)} = 4.07 \times 10^{-3}$ / °C



The polyester capacitor is designed with two metal plates where the polyester film is arranged between them; otherwise, a metalized film can be placed over the insulator.

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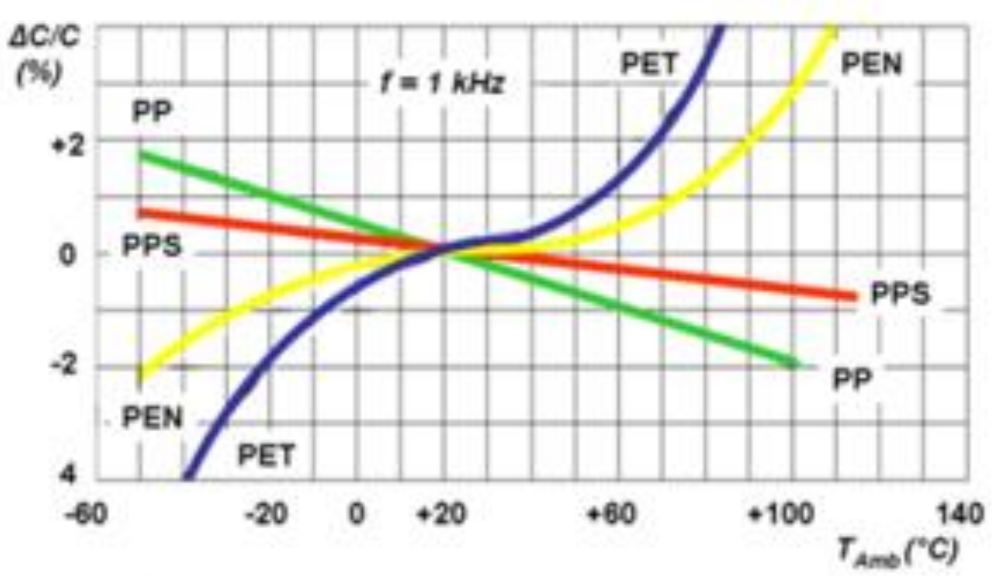
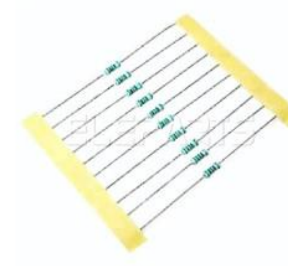
- The temperature coefficient of the material is positive.
- The polyester capacitor temperature coefficient is high.



3. Cryogenic temperature



- Type : Metal film Resistor

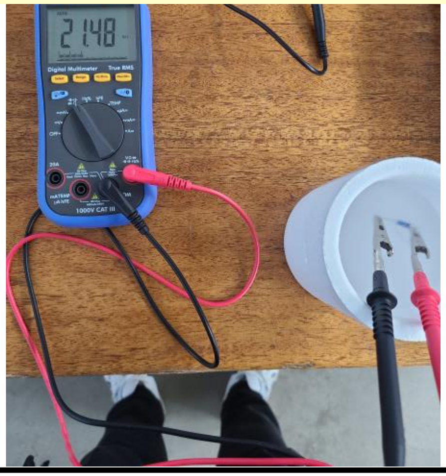
$$R = R_{ref}[1 + \alpha(T - T_{ref})]$$

What materials are composed in metal film resistor?

Select : Resitivity meas.
Range : Auto or proper

R_{ref} =55.6kΩ
T_{ref} = 20 °C
T = -195.8 °C
R = 55.2 kΩ

→ α = 0.036 x 10^{-3}

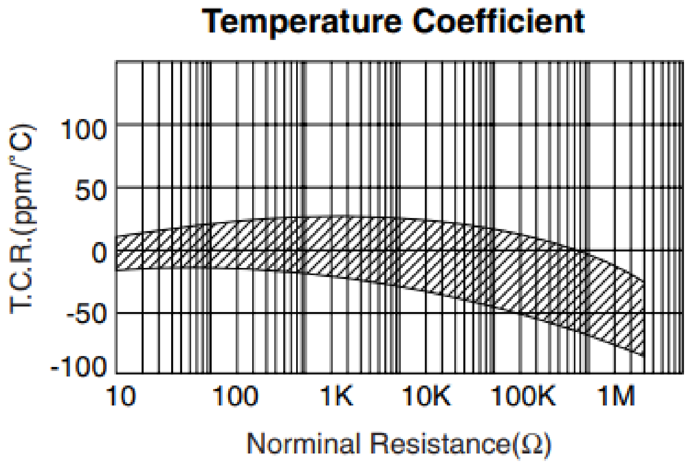


Resistivity and Temp Coefficient at 2(

Material	Resistivity ρ (ohm m)		Temperature coefficient α per degree C	σ x 10^7 /Ωm	Ref
Silver	1.59	$x10^{-8}$	.0038	6.29	3
Copper	1.68	$x10^{-8}$	.00386	5.95	3
Copper, annealed	1.72	$x10^{-8}$	.00393	5.81	2
Aluminum	2.65	$x10^{-8}$	.00429	3.77	1
Tungsten	5.6	$x10^{-8}$	.0045	1.79	1
Iron	9.71	$x10^{-8}$	.00651	1.03	1
Platinum	10.6	$x10^{-8}$	.003927	0.943	1
Manganin	48.2	$x10^{-8}$	.000002	0.207	1
Lead	22	$x10^{-8}$	...	0.45	1
Mercury	98	$x10^{-8}$	.0009	0.10	1
Nichrome (Ni,Fe,Cr alloy)	100	$x10^{-8}$	.0004	0.10	1
Constantan	49	$x10^{-8}$	...	0.20	1
Carbon* (graphite)	3-60	$x10^{-5}$	-.0005	...	1
Germanium*	1-500	$x10^{-3}$	-.05	...	1
Silicon*	0.1-60	...	-.07	...	1
Glass	1-10000	$x10^{9}$	...	...	1
Quartz (fused)	7.5	$x10^{17}$	...	...	1
Hard rubber	1-100	$x10^{13}$	...	...	1

3. Cryogenic temperature

- Metal Film Resistor 0.25Watt 56Kohm
- As the name indicates, the metal film resistor is made by depositing a thin layer of metal onto a ceramic former. The metal film acts in the same way as resistance wire, and as the thickness, width and length can be accurately controlled, the metal film resistor can be produced to a high tolerance.
- The metal that is deposited is normally **nickel chromium, NiCr**. which has small number of temperature coefficient, 0.4 x 10^{-3} / °C



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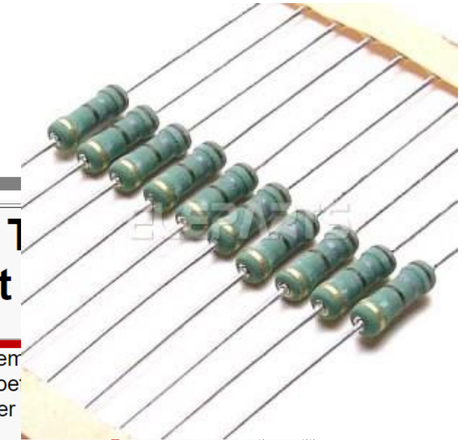
3. Cryogenic temperature



- Type : Metal Oxide Film Resistor

$$R = R_{ref}[1 + \alpha(T - T_{ref})]$$

What materials are composed in metal oxide film resistor?

R_{ref} =19.95 kΩ
T_{ref} = 20 °C
T = -195.8 °C
R = 21.47 kΩ

→ α = -0.35 x 10^{-3}

Resistivity and T
Coefficient

Material	Resistivity ρ (ohm m)		Tem coe per C		
Silver	1.59	$x10^{-8}$	.0038	6.29	3
Copper	1.68	$x10^{-8}$	.00386	5.95	3
Copper, annealed	1.72	$x10^{-8}$	.00393	5.81	2
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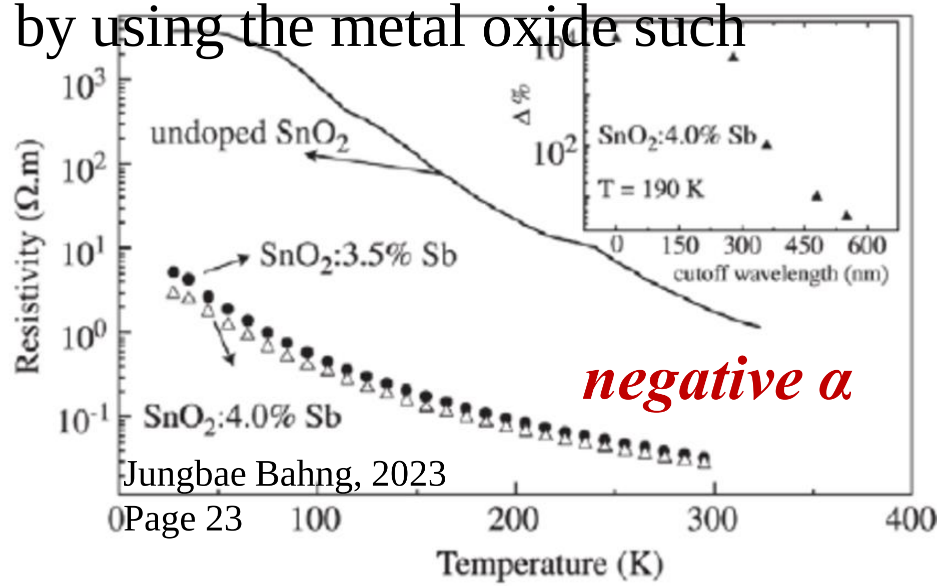
Carbon* (graphite)	3-60	$x10^{-5}$	-.0005	...	1
Germanium*	1-500	$x10^{-3}$	-.05	...	1
Silicon*	0.1-60	...	-.07	...	1
Glass	1-10000	$x10^{9}$	...	...	1
Quartz (fused)	7.5	$x10^{17}$	...	...	1
Hard rubber	1-100	$x10^{13}$	...	...	1

3. Cryogenic temperature

- Metal Oxide Film Resistor 1Watt 20Kohm
- The construction of metal oxide film resistor is almost similar to the metal film resistors. The main difference between the metal oxide film resistor and the metal film resistor is material used for constructing the film.
- In metal film resistor, the film is constructed by using the metals such as nickel chromium whereas in metal oxide film resistors, the film is constructed by using the metal oxide such as tin oxide.
- Material : tin oxide



negative α


THANK YOU
FOR YOUR
ATTENTION