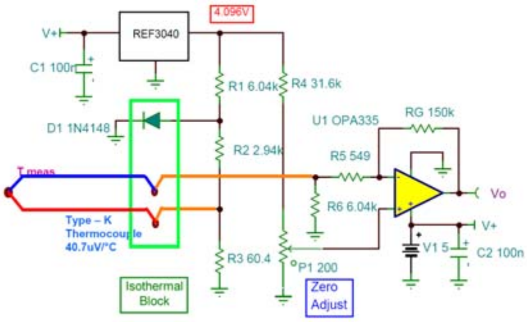
Thermoelectric Laws and Thermocouple Applications



Thermocouple:

A junction of two dissimilar metals

- If two junctions are at different temperatures, a voltage develops across the junction
  - Charged carriers diffuse from hot to cold
  - Carriers leave behind opposite charge
    - Voltage
- Voltage is a function of ΔT
- No external power required!

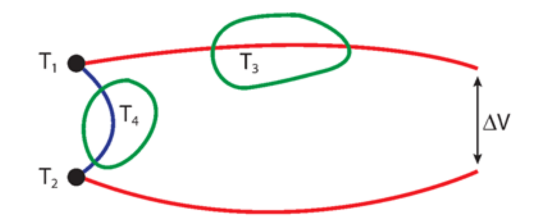
Thermoelectric Laws

- Let's consider what does and does not affect the operation of a thermocouple
- For example, must we account for the EMF created by another junction that connects the thermocouple to an amplifier or to a data logger?

Law of Homogeneous Materials (#1)

- The thermal EMF of a thermocouple is unaffected by temperatures elsewhere in the circuit if the two metals of the thermocouple are homogeneous
- This law allows us to make the thermocouple leads out of the thermocouple material
- For example, the lead wires can be copper and constantan (a type T thermocouple)

Law of Homogeneous Materials (#1)

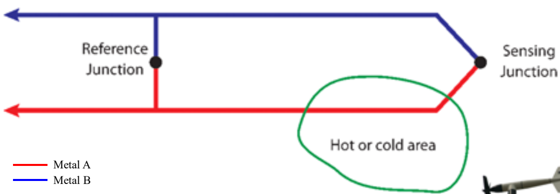


Temperatures T_3 and T_4 will not affect the EMF created by the temperature difference at the thermocouple junctions

Metal A
Metal B

Law of Homogeneous Materials (#1)

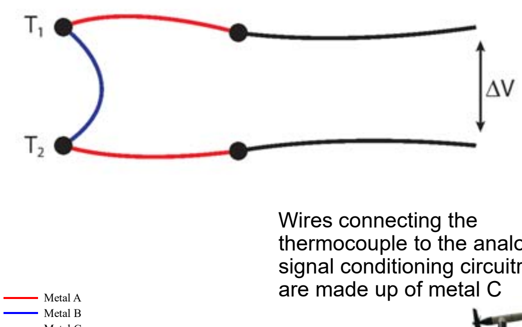
In other words, temperature changes in the wiring between the input and output do not affect the output voltage, provided the wire is made of a thermocouple alloy



Law of Intermediate Materials (#2)

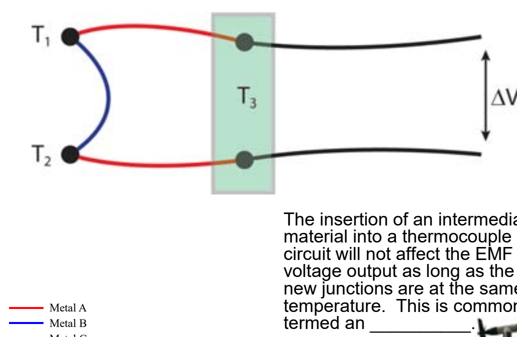
- If a third metal is inserted in either wire A or B and if the two new junctions are at the same temperature, there will be no net voltage generated by the new metal
- This allows us to connect a thermocouple to an amplifier or to a voltmeter
- Without this property, a thermocouple would be useless!

Law of Intermediate Materials (#2)



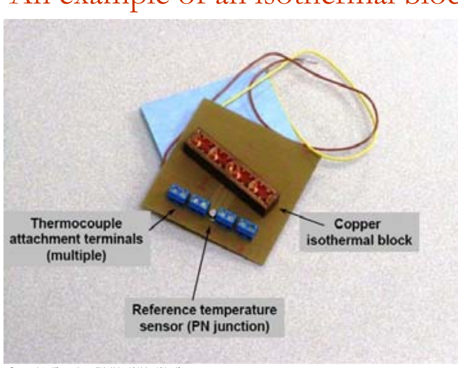
Wires connecting the thermocouple to the analog signal conditioning circuitry are made up of metal C

Law of Intermediate Materials (#2)



The insertion of an intermediate material into a thermocouple circuit will not affect the EMF voltage output as long as the two new junctions are at the same temperature. This is commonly termed an ___________.

An example of an isothermal block



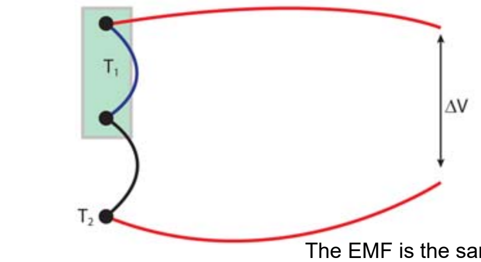
Source: http://focus.ti.com/lit/ml/slyp161/slyp161.pdf

Law of Intermediate Materials (#3)

- If metal C is inserted into the junction AB, no net voltage is generated as long as junction AC and BC are at the same temperature

- This allows us to use a third metal (e.g., solder) to electrically and physically bond the two thermocouple metals

Law of Intermediate Materials (#3)



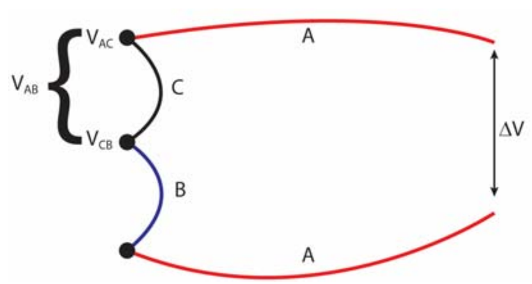
Metal A
Metal B
Metal C/Solder

The EMF is the same with or without the solder as long as the junctions are electrically sound

Law of Intermediate Materials (#4)

- Thermocouple voltages of two metals A and B with respect to a third metal C may be added to form thermocouple voltages with respect to each other
- This allows us to calibrate new thermocouple metal combinations given known standards

Law of Intermediate Materials (#4)



Metal A
Metal B
Metal C

$V_{AB} = V_{AC} + V_{CB}$

Law of Successive or Intermediate Temperatures (#5)

- If a thermocouple produces a voltage ΔV_a for junction temperatures T_1 and T_2, and
- If the same thermocouple produces a voltage ΔV_b for junction temperatures T_2 and T_3, then
- The thermocouple will produce a voltage $\Delta V_a + \Delta V_b$ for junction temperatures T_1 and T_3.

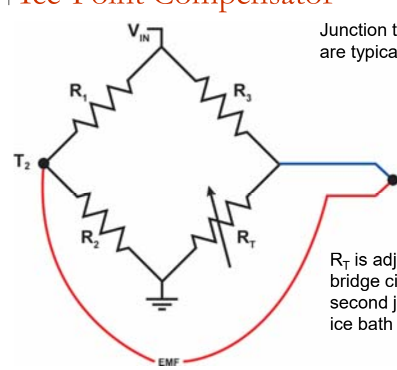
This means that we can use standard tables or equations, even if the reference junction is not at 0°C

How do we determine temperature?

- Thermocouples measure temperature differences
- We need to know one of the junction temperatures to be able to calculate the other
- How do we accomplish this?
  - Place one junction in an ice bath (0°C)
  - Place one junction in a temperature controlled chamber (oven)
  - Use a secondary temperature measurement
  - Use an electronic substitute for a reference

Ice-Point Compensator

Junction temperature errors are typically less than ±0.2°C

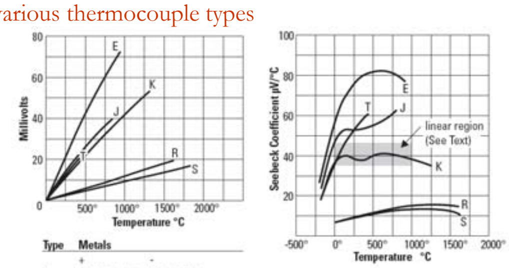


R_T is adjusted such that the bridge circuit acts as the second junction placed in an ice bath at 0°C

Question: Why don't we use the reference transducer (e.g., thermistor, platinum RTD, semiconductor, etc.) to measure the temperature in the first place?

Blatantly copied from http://focus.ti.com/lit/ml/slyp161/slyp161.pdf

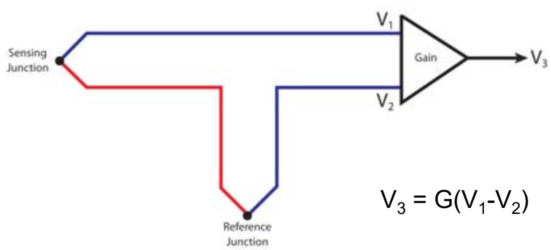
Temperature vs. voltage and Seebeck coefficient for various thermocouple types



Type	Metals +		-
E	Chromel	vs.	Constantan
J	Iron	vs.	Constantan
K	Chromel	vs.	Alumel
R	Platinum	vs.	Platinum 13% Rhodium
S	Platinum	vs.	Platinum 10% Rhodium
T	Copper	vs.	Constantan

Source: Agilent Technologies, Application Note 290

Amplifying a weak signal



$V_3 = G(V_1\text{-}V_2)$

Determining the correct gain

- We want to measure the temperature using a copper-constantan thermocouple such that:
  - Range: –15°C to 35°C
  - T_2 = 0°C
  - Output: –5 V < V_3 < 5 V

Problems with large gain:

- Potentially expensive
- Susceptible to noise

Characteristics of thermocouples

- Good points
  - Very small
  - Inexpensive
  - Fast response
  - Reliable
  - Accurate
  - Simple to use
- Drawbacks
  - Small output signal
  - Need known reference
  - Metal corrosion
  - Poor sensitivity
  - Metal fatigue
  - Some residual non-linearity

Thermocouple applications

- Micrometeorology
  - High-speed measurements
  - Turbulence
  - Plant physiology

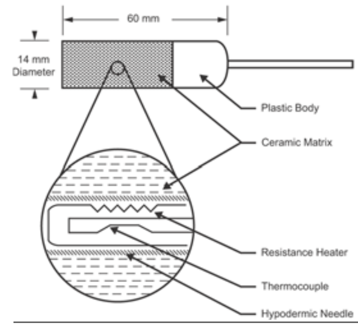
Source: http://www.campbellsci.ca/Products_SystemsBR_F.html

Large thermocouple boundary layer rake

Source: http://www.grc.nasa.gov/WWW/RT2000/5000/5850hwang.html

Thermocouple applications

- Soil moisture – Campbell Scientific 229-L

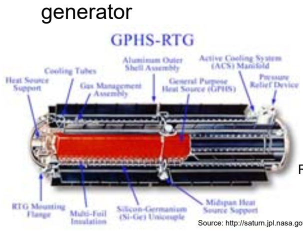


Thermopile applications

A thermopile is made by connecting multiple thermocouples in series or in parallel

- Pyranometer
- Radioisotope thermoelectric generator

Source: http://snrs.unl.edu/agmet/408/instruments/shortrad.html



RTG supplying electrical power for the Cassini spacecraft

Source: http://saturn.jpl.nasa.gov/spacecraft/safety.cfm