MM215 Experiment-5 & 6

Calibration, Accuracy & Precision

Calibration of sensors

Exp 5: Force sensor
Load cell

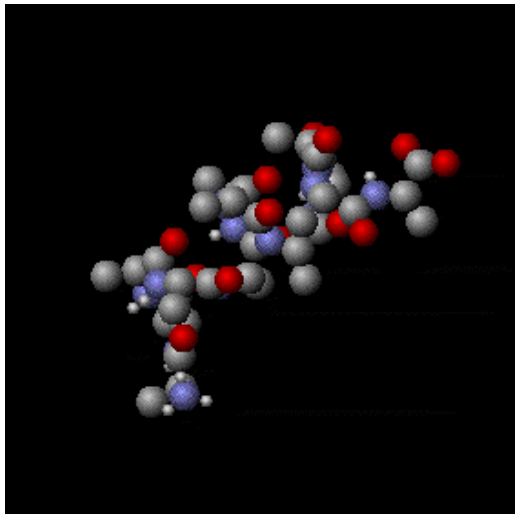
Exp 6: Temperature sensors
Thermocouple (Type K)
Thermistor (NTC)

1) Temperature sensors

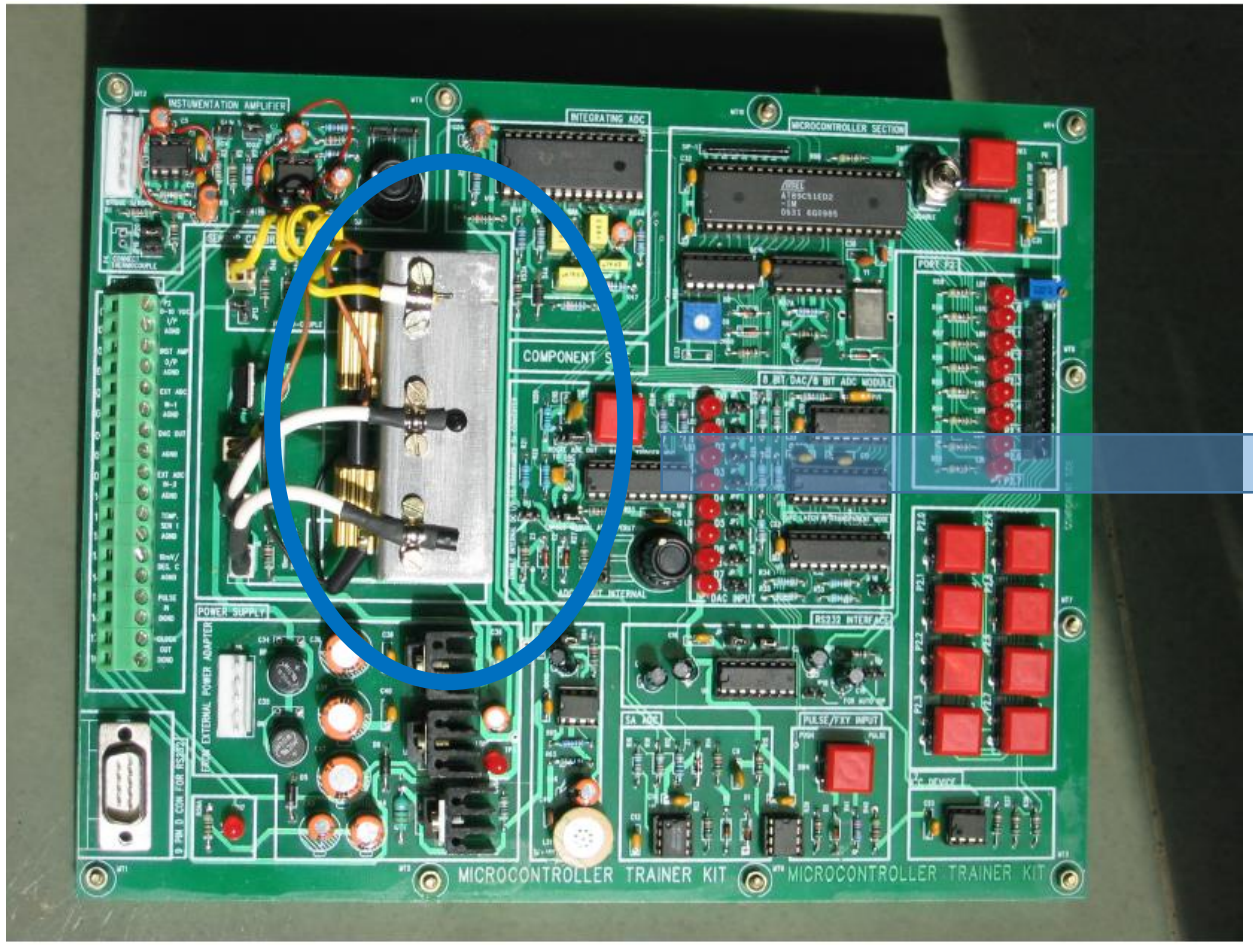
What is temperature?

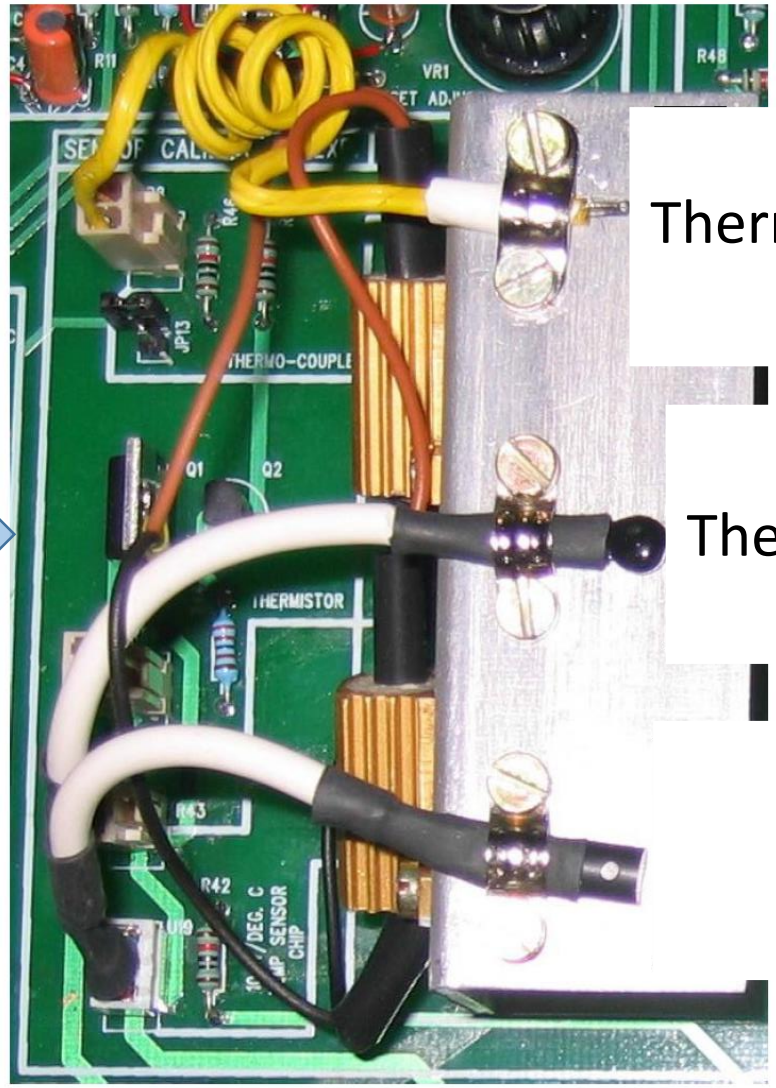
Temperature *is an objective comparative measure of hot or cold.*

Absolute temperature of a material is proportional to the average kinetic energy of the microscopic motions of their constituent microscopic particles



Temperature sensors in the Microcontroller Kit





Thermocouple

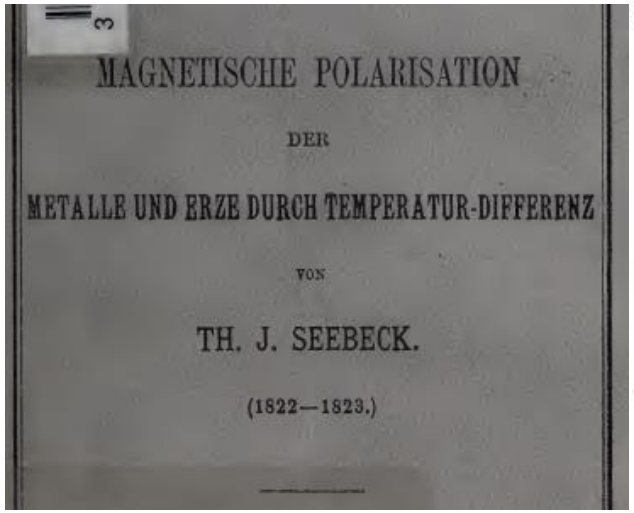
Thermistor

Temperature measurement

1) Thermocouple

Seebeck Effect

Thomas Johann Seebeck
* 09.04.1770; † 10.12.1831



3

MAGNETISCHE POLARISATION

DER

METALLE UND ERZE DURCH TEMPERATUR-DIFFERENZ

VON

TH. J. SEEBECK.

(1822—1823.)

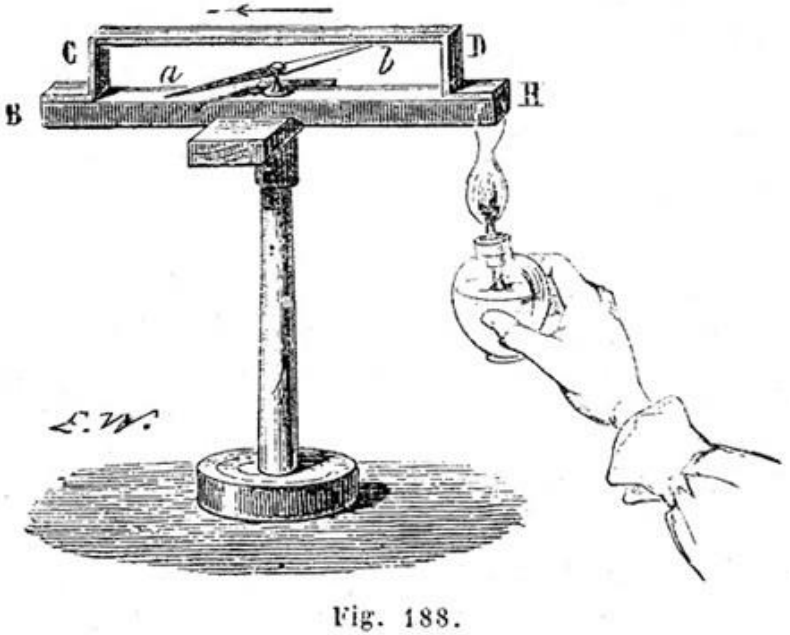
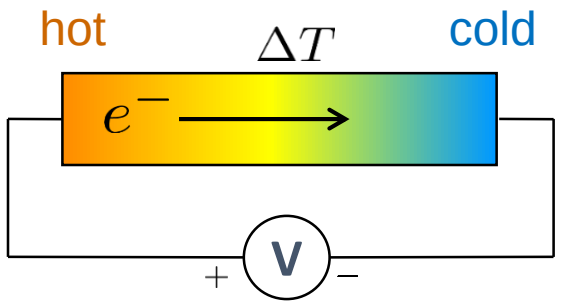


Fig. 188.

1821

An electrical potential (voltage) is generated within any isolated conducting material that is subjected to a temperature gradient; this is the ***absolute Seebeck effect, ASE.***

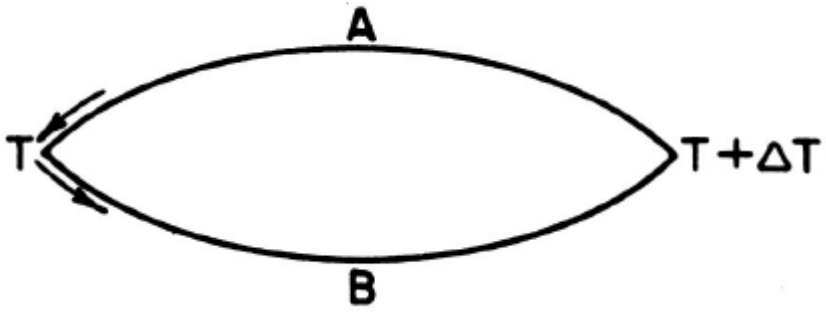
Seebeck Effect



$$S = \frac{U}{\Delta T}$$

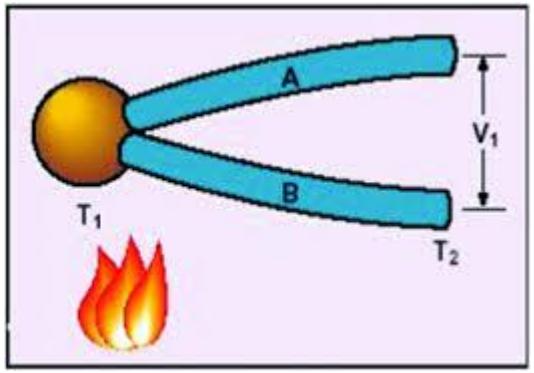
Unit: V/K, μV/K

- Thermal diffusion of the electron gas
- Warmer carriers have higher energy
- Charge carriers move from the hot end to the cold end
- **Material property and not a property of the junction**
- For n-type: $S < 0$, p-type: $S > 0$
- Reason for using p-n pairs



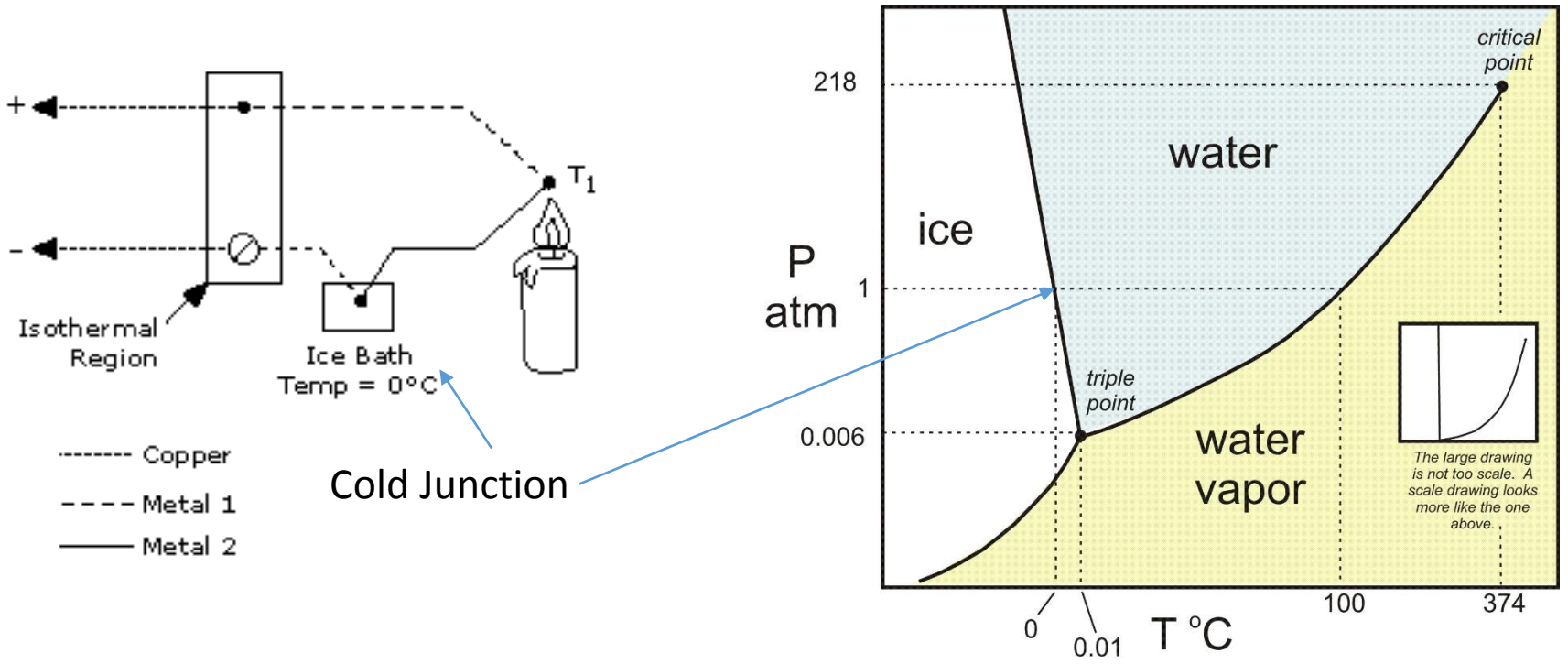
$$U = (S_A - S_B)\Delta T$$

Temperature measurement- thermocouple



Temperature measurement- thermocouple

Requirement of a fixed Temperature point



Temperature measurement- thermocouple

Standard Calibration Chart – Type K thermocouple

MAXIMUM TEMPERATURE RANGE

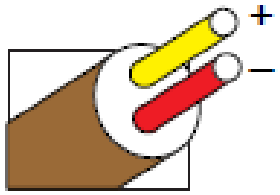
Thermocouple Grade
– 328 to 2282°F
– 200 to 1250°C

Extension Grade
32 to 392°F
0 to 200°C

LIMITS OF ERROR
(whichever is greater)
Standard: 2.2°C or 0.75% Above 0°C
2.2°C or 2.0% Below 0°C
Special: 1.1°C or 0.4%

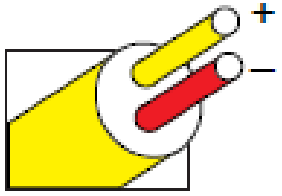
COMMENTS, BARE WIRE ENVIRONMENT:
Clean Oxidizing and Inert; Limited Use in Vacuum or Reducing; Wide Temperature Range; Most Popular Calibration

TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C



Thermocouple Grade

Nickel-Chromium
vs.
Nickel-Aluminum



Extension Grade

Revised Thermocouple Reference Tables

TYPE K

Reference Tables
N.I.S.T.
Monograph 175
Revised to
ITS-90

Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-6.458	-6.457	-6.456	-6.455	-6.453	-6.452	-6.450	-6.448	-6.446	-6.444	-6.441	-260
-250	-6.441	-6.438	-6.435	-6.432	-6.429	-6.425	-6.421	-6.417	-6.413	-6.408	-6.404	-250
-240	-6.404	-6.399	-6.393	-6.388	-6.382	-6.377	-6.370	-6.364	-6.358	-6.351	-6.344	-240
-230	-6.344	-6.337	-6.329	-6.322	-6.314	-6.306	-6.297	-6.289	-6.280	-6.271	-6.262	-230
-220	-6.262	-6.252	-6.243	-6.233	-6.223	-6.213	-6.202	-6.192	-6.181	-6.170	-6.158	-220
-210	-6.158	-6.147	-6.135	-6.123	-6.111	-6.099	-6.087	-6.074	-6.061	-6.048	-6.035	-210
-200	-6.035	-6.021	-6.007	-5.994	-5.980	-5.965	-5.951	-5.936	-5.922	-5.907	-5.891	-200
-190	-5.891	-5.876	-5.861	-5.845	-5.829	-5.813	-5.797	-5.780	-5.763	-5.747	-5.730	-190
-180	-5.730	-5.713	-5.695	-5.678	-5.660	-5.642	-5.624	-5.606	-5.588	-5.569	-5.550	-180
-170	-5.550	-5.531	-5.512	-5.493	-5.474	-5.454	-5.435	-5.415	-5.395	-5.374	-5.354	-170
-160	-5.354	-5.333	-5.313	-5.292	-5.271	-5.250	-5.228	-5.207	-5.185	-5.163	-5.141	-160
-150	-5.141	-5.119	-5.097	-5.074	-5.052	-5.029	-5.006	-4.983	-4.960	-4.936	-4.913	-150
-140	-4.913	-4.889	-4.865	-4.841	-4.817	-4.793	-4.768	-4.744	-4.719	-4.694	-4.669	-140

°C	0	1	2	3	4	5	6	7	8	9	10	°C
250	10.153	10.194	10.235	10.275	10.316	10.357	10.398	10.439	10.480	10.520	10.561	250
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971	260
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	11.382	270
280	11.382	11.423	11.465	11.505	11.547	11.588	11.630	11.671	11.712	11.753	11.795	280
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	12.209	290
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	12.624	300
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	13.040	310
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	13.457	320
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	13.874	330
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	14.293	340
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	14.713	350
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	15.133	360
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	15.554	370
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	15.975	380
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	16.397	390
400	16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778	16.820	400

Temperature measurement- thermocouple

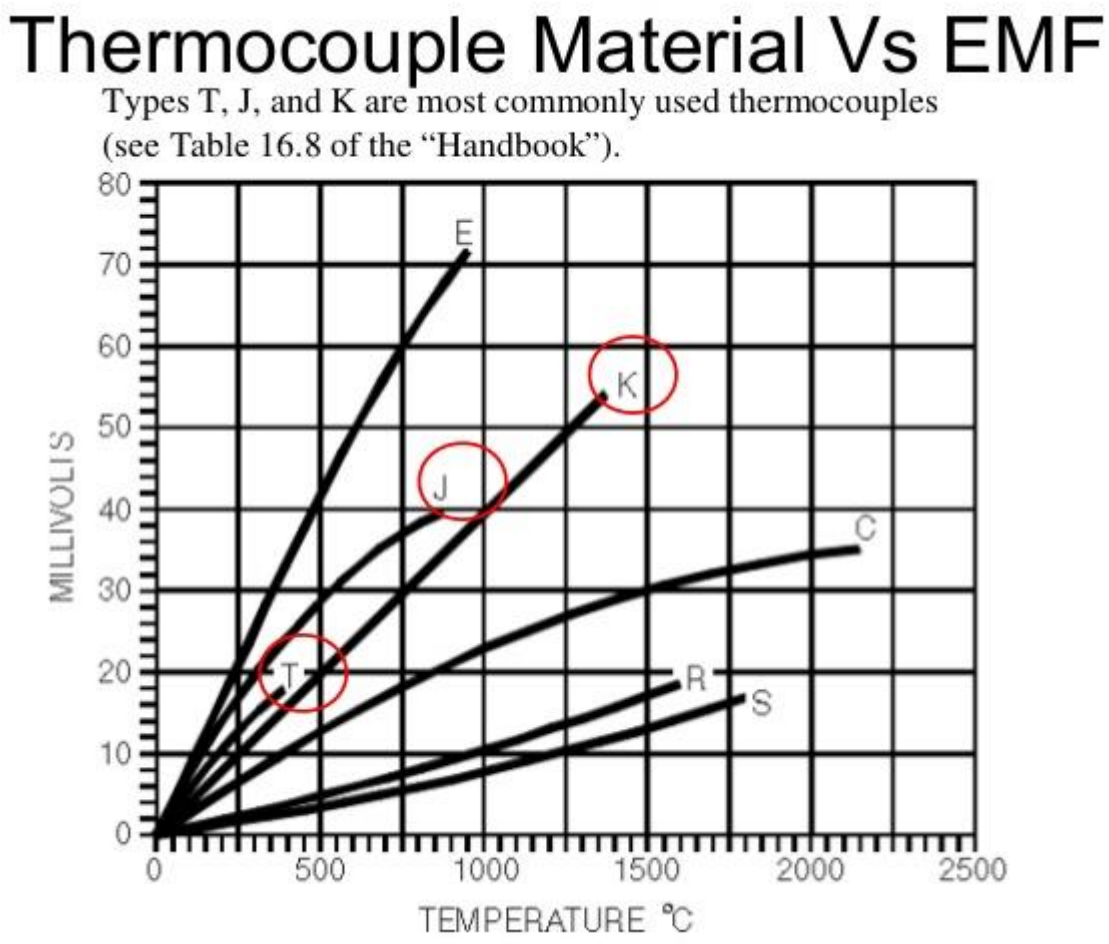
TABLE 1 COMPARISON OF THERMOCOUPLE TYPES

Thermocouple type	Conductors	Temperature range (°C)	Typical specified temperature range (°C)	Seebeck coefficient at 20°C (μV/°C)	Application environments
E	Chromel (+) constantan (–)	–270 to +1000	–200 to +900	62	Oxidizing, inert, vacuum
J	Iron (+) constantan (–)	–210 to +1200	0 to 760	51	Caccuum, oxidiz-ing, reducing, inert
T	Copper (+) constantan (–)	–270 to +400	–200 to +371	40	Corrosive, moist, subzero
K	Chromel (+) alumel (–)	–270 to +1370	–200 to +1260	40	Inert
N	Nicrosil (+) nisil (–)	–270 to +1300	0 to 1260	27	Oxidizing
B	Platinum (30% rhodium)(+) Platinum (6% rhodium) (–)	0 to 1820	0 to 1820	1	Oxidizing, inert
S	Platinum (10% rhodium) (+) platinum (–)	–50 to +1760	0 to 1480	7	Oxidizing, inert
R	Platinum (13% rhodium) (+) platinum (–)	–50 to +1760	0 to 1480	7	Oxidizing, inert

How accurately can the temperature be measured?

Temperature measurement- thermocouple

EMF vs T trend



Temperature measurement- Thermistor

- Temperature sensing based on **change of Resistance with Temperature**.
- Typically **semiconductors** are used which have a negative temperature coefficient (NTC)

$$R = (1/\sigma).(l/A)$$

Electrical conductivity

Sample dimensions

$$\sigma = ne\mu$$

carrier mobility

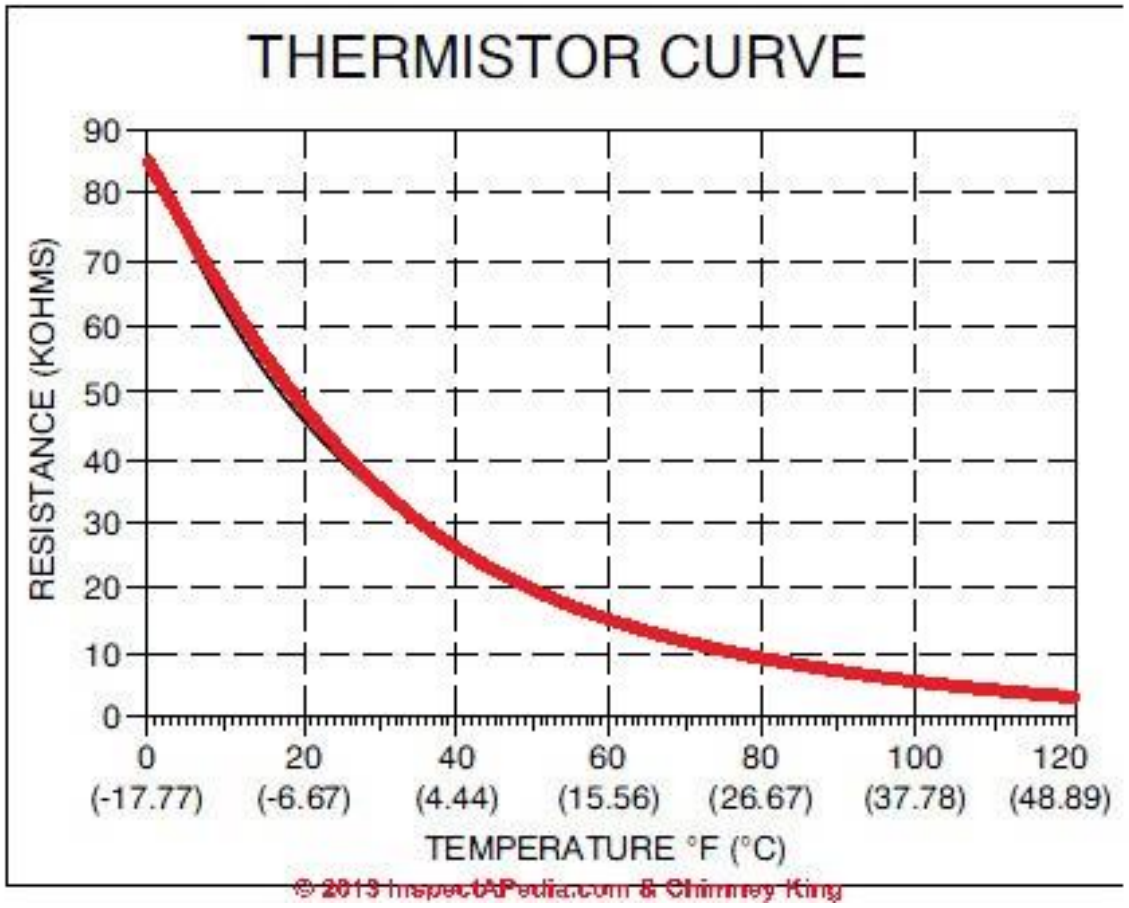
Charge carrier concentration

Temperature measurement- Thermistor

Temperature dependencies

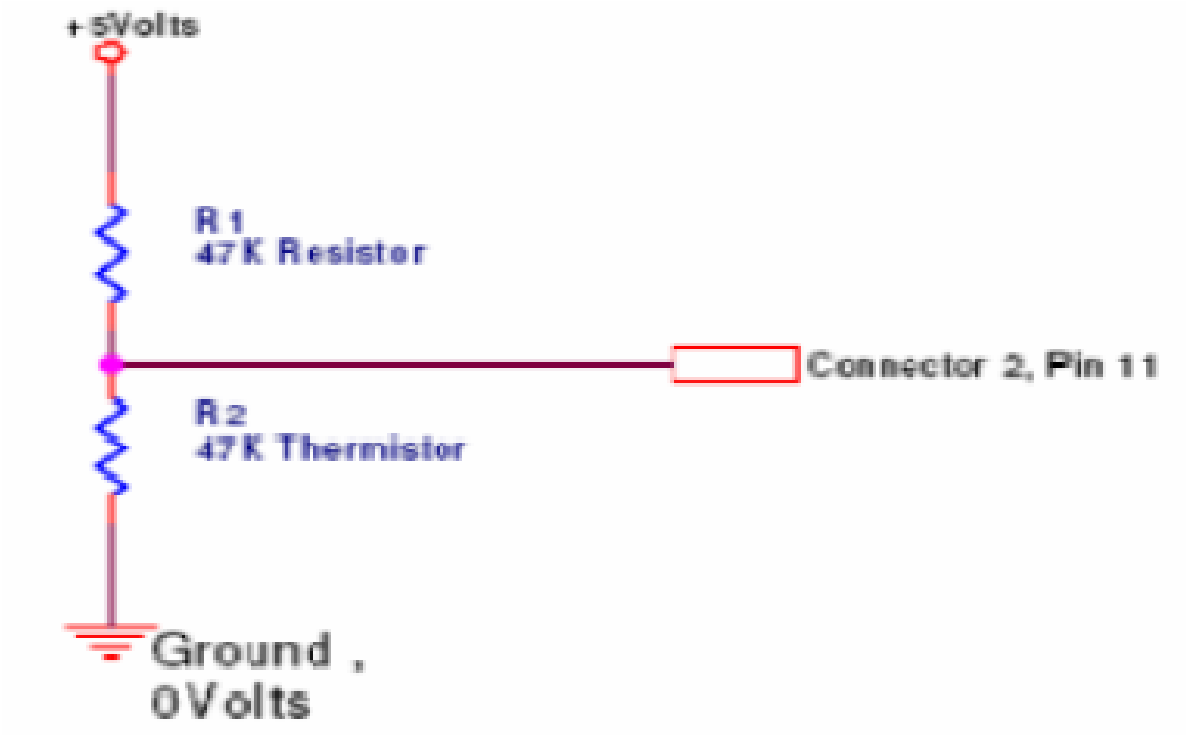
$$n = n_0 \exp(-\frac{E_G}{2k_B T})$$

$$\mu = 1/T^x$$



Temperature measurement- Thermistor

Resistance Measurement



Temperature measurement- Thermistor

Calibration

Steinhart–Hart equation

$$\frac{1}{T} = A + B\ln(R) + C[\ln(R)]^3,$$

T – temperature (K)
R- resistance (Ω)
A,B,C- Steinhart-Hart coefficients

Resistance	Temperature
10500	9.13
3200	35.56
700	77.02

$$\begin{pmatrix} 1 & 9.259 & 793.799 \\ 1 & 8.071 & 525.735 \\ 1 & 6.551 & 281.15 \end{pmatrix} \begin{pmatrix} A \\ B \\ C \end{pmatrix} = \begin{pmatrix} 3.542 \times 10^{-3} \\ 3.239 \times 10^{-3} \\ 2.856 \times 10^{-3} \end{pmatrix}$$

Term	3-point Fit
A	$1.236*10^{-3}$
B	$2.453*10^{-4}$
C	$4.389*10^{-8}$

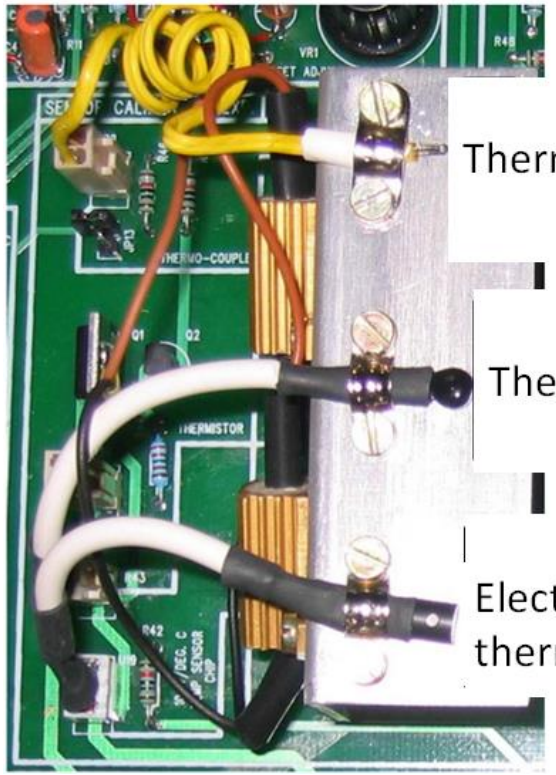
Temperature measurement- Thermistor

Calibration (Simplification)

$$\frac{1}{T} = A + B\ln(R)$$

T calculated from R

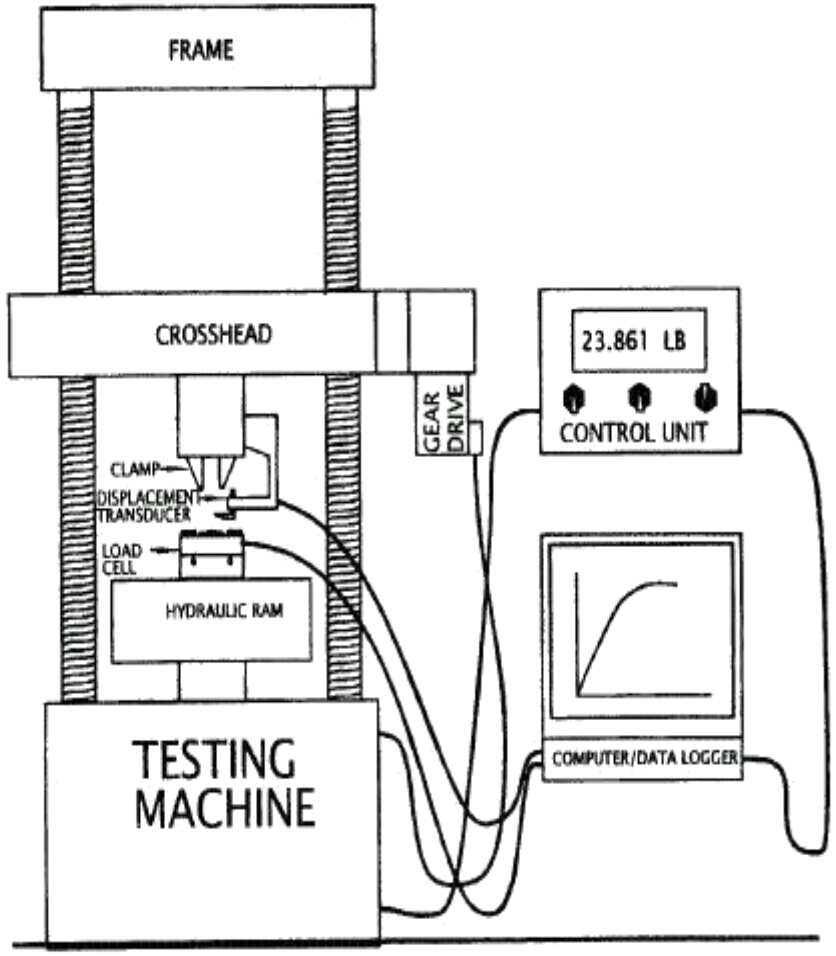
Exp 6 – temperature calibration



1 ^{0}C = 10 mV

Sr. No.	Temperature indicated by semiconductor sensor	Voltage indicated by thermocouple x 100	Voltage indicated by thermistor
1	300mv**(30.0°C)**	?	?
2	321mv**(32.1°C)**	?	?
3	339mv**(33.9°C)**	?	?
4	**…**	…	…

Force sensor (Load Cell)

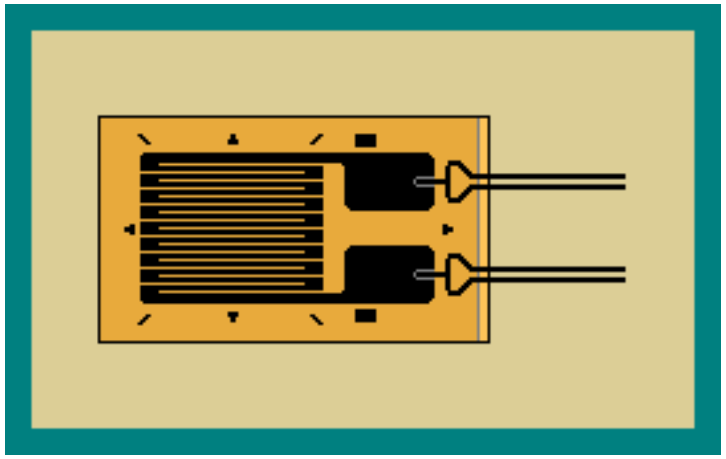


Mechanical Testing

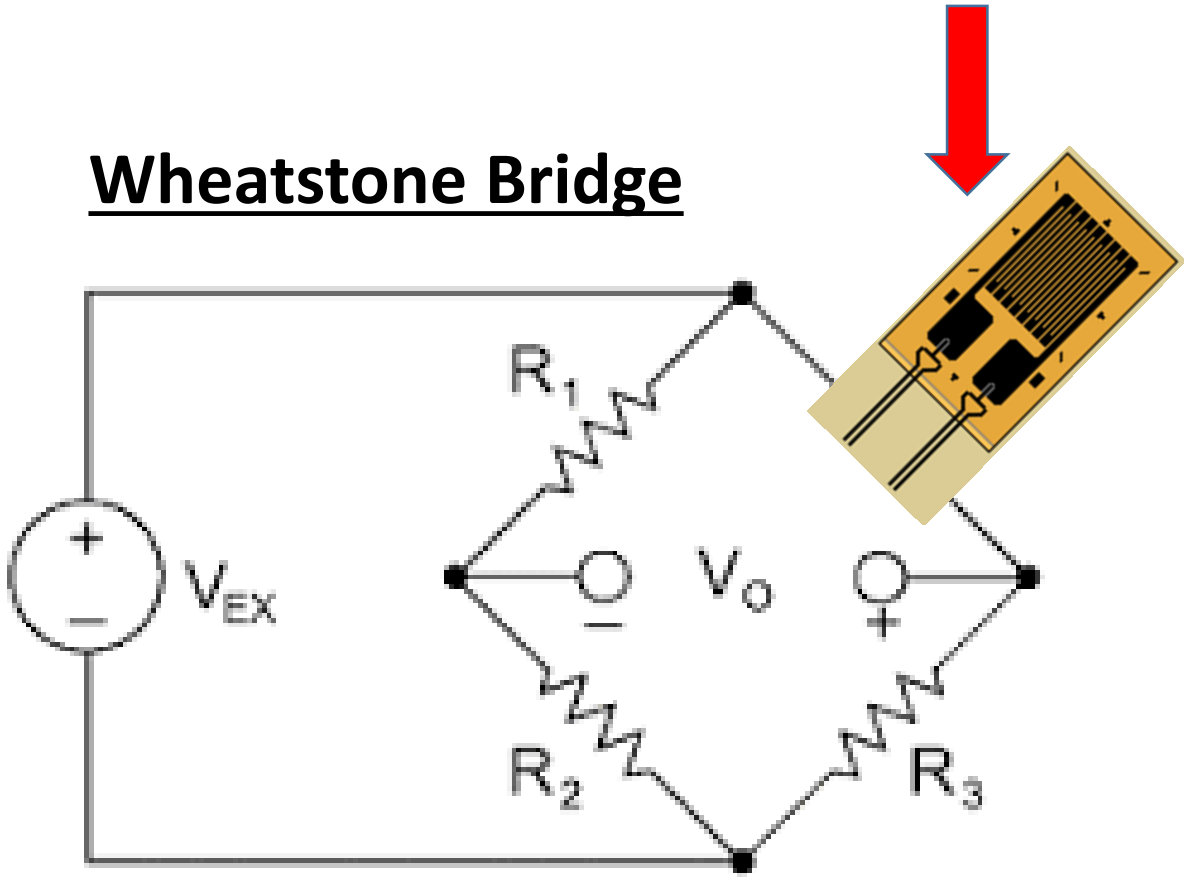
Electronic Balance

Force sensor (Load Cell)

Strain Gauge – Change in resistance with stress

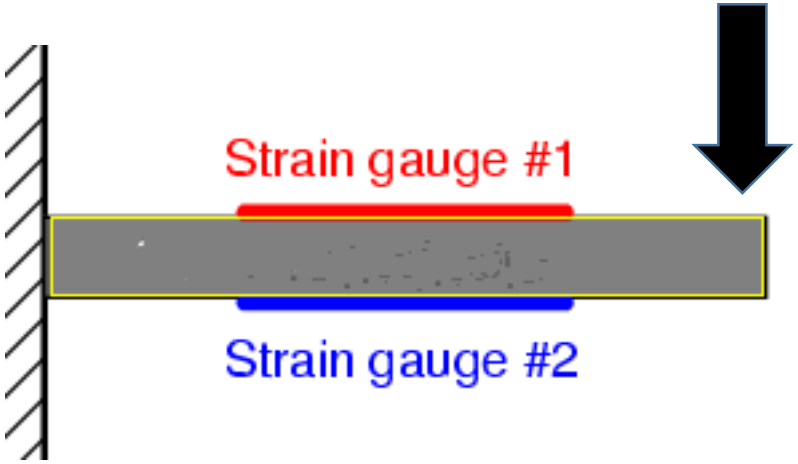


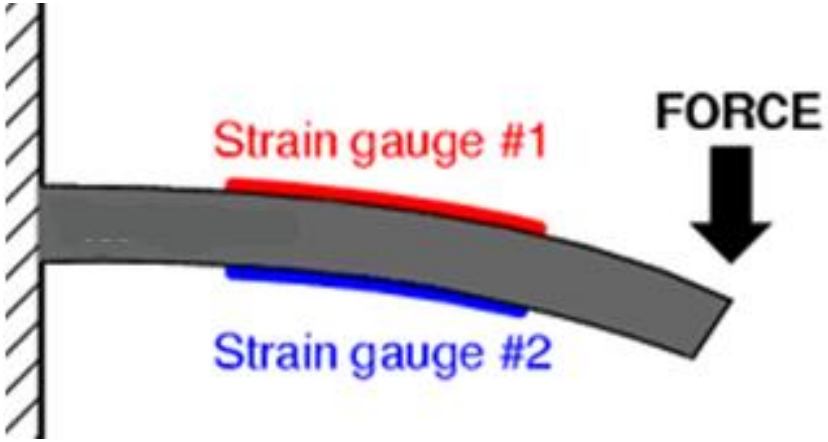
Wheatstone Bridge

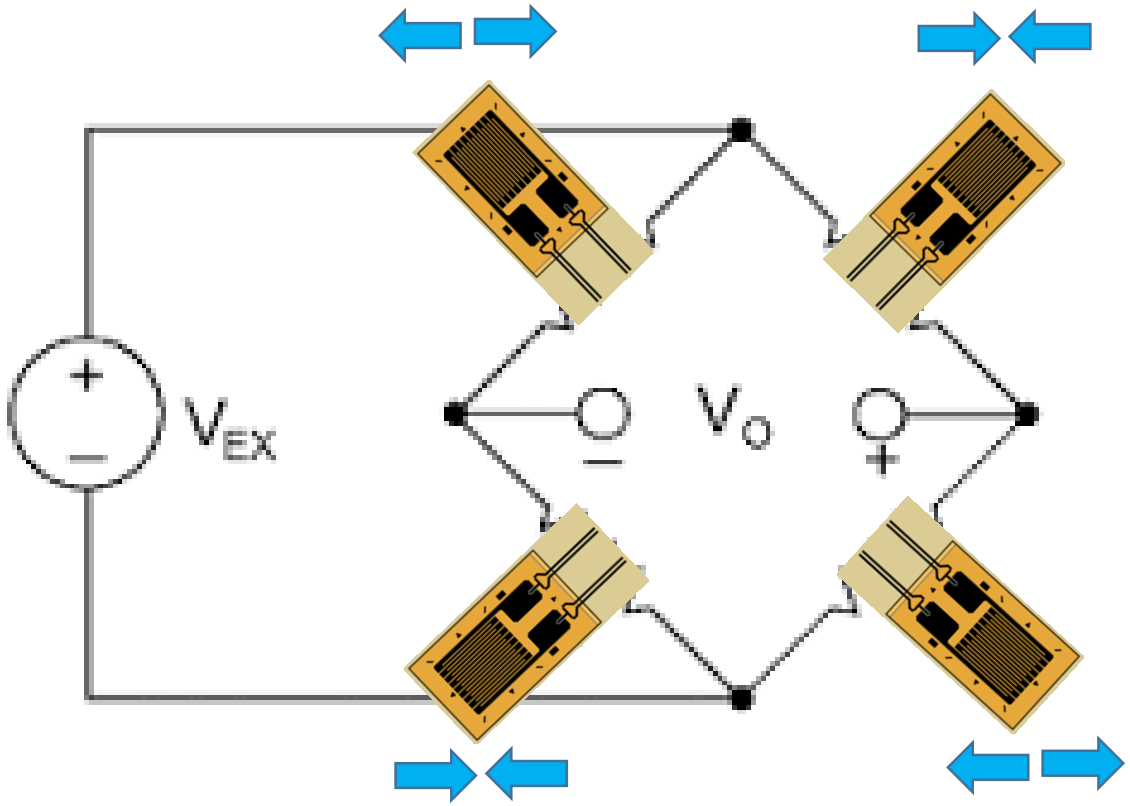


Force sensor (Load Cell)

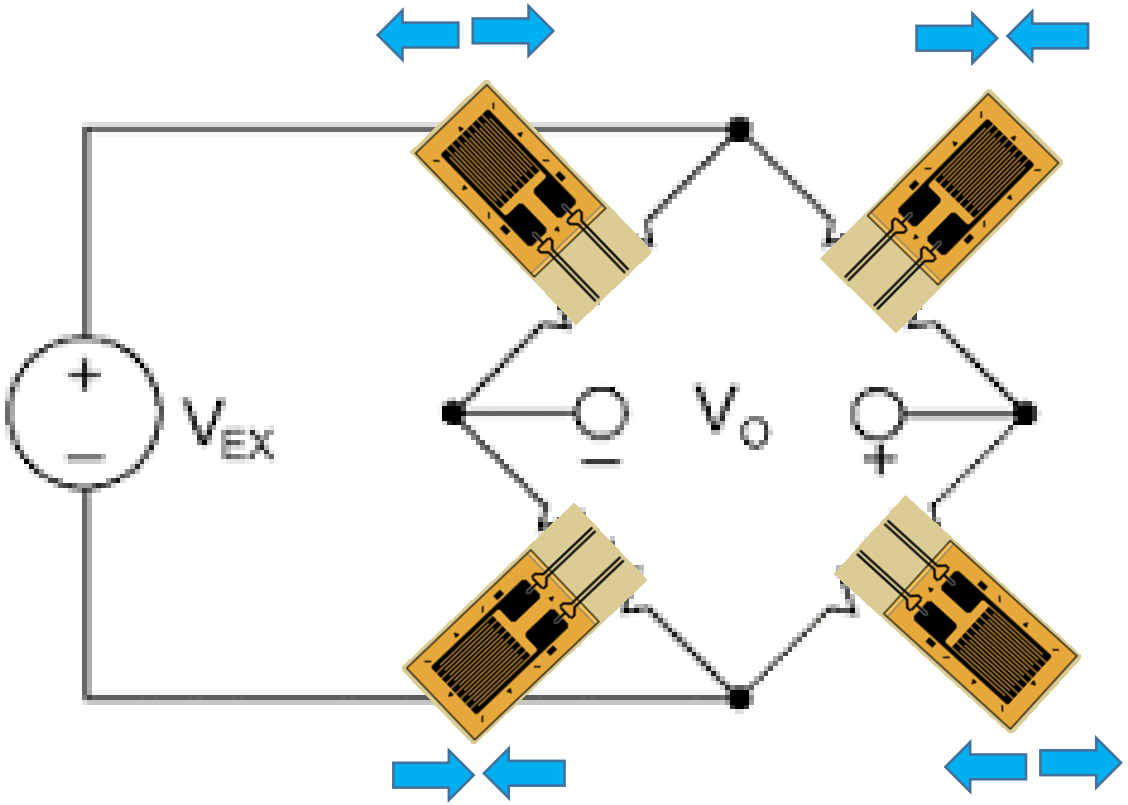
Cantilever Type



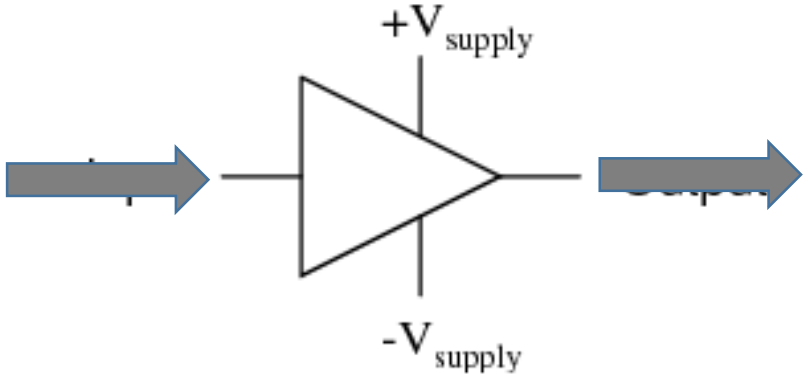




Load Cell Calibration (Exp 5)



Amplifier



Load Cell Calibration (Exp 5)

Gain Select

Offset Potentiometer

Load Cell Calibration (Exp 5)

Specifications of the Load cell

- Rated Capacity - 11.77N(1.2Kgf)
- Rated Output - 0.9 mV/V ±0.1mV/V
- Excitation Voltage – 10 V