An Experiment to Determine the Affect of varying Temperature on the Resistance of Strain Gage.

Imran Hanif, Syed Ali Raza, M. Sabieh Anwar

Motivation:

A ratiometer is a device that determines the percentage of ortho and para hydrogen, the two different quantum states of hydrogen. Based on the difference of thermal conductivity of the two states we can determine the ratio of the two gases.
We needed some device for calculating the energy Q which travels between the hot plate and the cold plate to determine the conductivity of the gas in our ratio meter. When the temperature of the metal plate (hot plate) is changed, there is a resistance change in the strain gage, by a negative feedback system we pass current through the strain gage to compensate the change and maintain a constant resistance, and the strain gage is used as a sensitive heating element. Here is an experiment to determine the strain brought on by a change in temperature.

The Experiment:

Strain Gage:

A resistance strain gauge is a strip with maize like metallic wiring pattern 5 µm thick of constantan (copper-nickel alloy) on a thin foil of polyamide. Strain gauge is fixed on the base material whose strain is to be measured with the help of special epoxy. Mechanical and thermal stresses act on the material and the materials dimension change either elongating or contracting and correspondingly the strain gauge wires expand or contract and its resistance changes.
Strain is defined as

$$\epsilon = \Delta L/L$$

Strain gauge sensitivity is calibrated with F_G

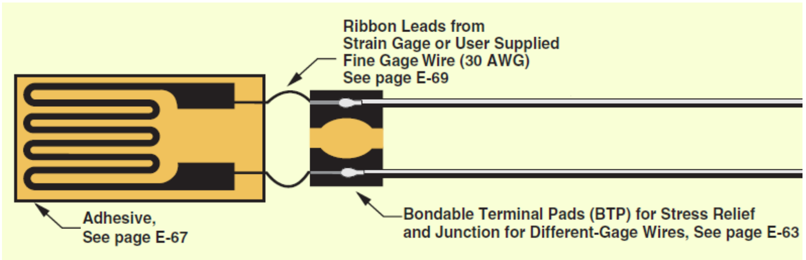
$$F_G = (\Delta R/R) /(\Delta L/L)$$
$$F_G = \Delta R/R / \varepsilon$$

Where

$$R = \rho L/A$$

ρ = resistivity of the material
L= Length of wire
A = Cross sectional area

An aluminum strip was taken and scrubbed with acetone, special bonding epoxies were applied and an Omega Precision Strain Gage (**SGD-1.5/120-LY11**) was bonded to it. Bondable Terminal Pads (BTP's) were glued and the strain gage wires soldered to it. Two thin copper wires were soldered to these pads and were covered with heat resistant sleeves. Strain gauge detects a micro level change in resistance and for that purpose a Wheatstone bridge circuit was employed to convert the resistance change to voltage change. Strain gauge with two wires connected with one side of bridge with three fixed resistances to make a quarter bridge for general stress measurements.

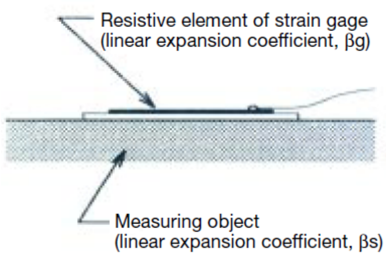


Temperature Compensation:

Here is how the strain gages are temperature compensated in the service temperature range. With the self-temperature-compensation gage, the temperature coefficient of resistance of the sensing element is controlled based on the linear expansion coefficient of the measuring object. Thus, the gage enables strain measurement without receiving any thermal effect if it is matched with the measuring object. Suppose that the linear expansion coefficient of the measuring object is **βs** and that of the resistive element of the strain gage is **βg**. When the strain gage is bonded to the measuring object as shown in the figure below, the strain gage bears thermally induced apparent strain/°C, **ϵ**, as follows[1]:

$$\epsilon_{thermal} = \alpha / F_G + (\beta s - \beta g)$$

α : Temperature coefficient of resistance of resistive element
F_G : Gage factor of strain gage



The gage factor, F_G, is determined by the material of the resistive element, and the linear expansion coefficients, **βs** and **βg**, are determined by the materials of the measuring object and the resistive element, respectively. Thus, controlling the temperature coefficient of resistance, **α**, of the resistive element suffices to make the thermally-induced apparent strain, **ϵT**, zero in the above equation.

For $\epsilon_{thermal} = 0$.

$$\alpha = -F_G\,(\beta s - \beta g)$$

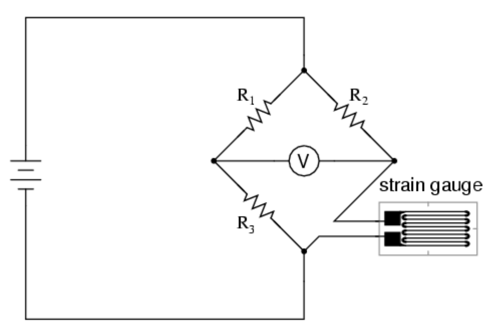
The temperature coefficient of resistance, **α,** of the resistive element can be controlled through heat treatment in the foil production process. Since it is adjusted to the linear expansion coefficient of the intended measuring object, application of the gage to other than the intended materials not only voids temperature compensation but also causes large measurement errors, which must be systematically corrected.

The service temperature range is the range of ambient temperature where the use of the strain gages is permitted without permanent changes of the measurement properties. The service temperature of our strain gage is -75 to 200°C according to the data sheet.

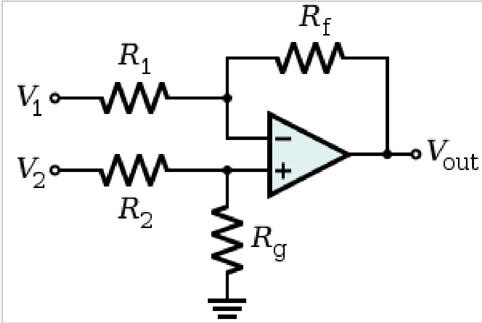
Circuit Design

We used a Wheatstone bridge to detect the small changes in resistance of the strain gage. A 1.5V is applied to power the wheat stone bridge, a volt meter is connected across the bridge as shown in the diagram. We vary the resistance of the variable resistance (R2) so that the volt meter shows zero volts and the bridge is balanced. Now a small change in resistance of the strain gage would show on the voltmeter.

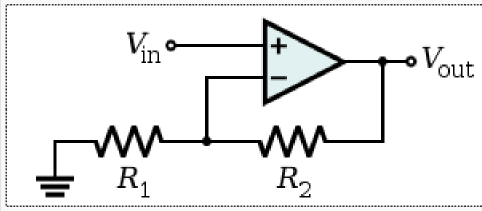
Quarter-bridge strain gauge circuit



The voltage changes are extremely minute and hence we have to amplify them. We used UA741 OP-AMP to make a differential amplifier which takes the difference between the outputs and also some noise is cancelled out when the difference of the two voltages is taken. This was connected to a non inverting amplifier with a gain set to 100. The Op-Amps are powered by a constant DC supply of 9 volts each.

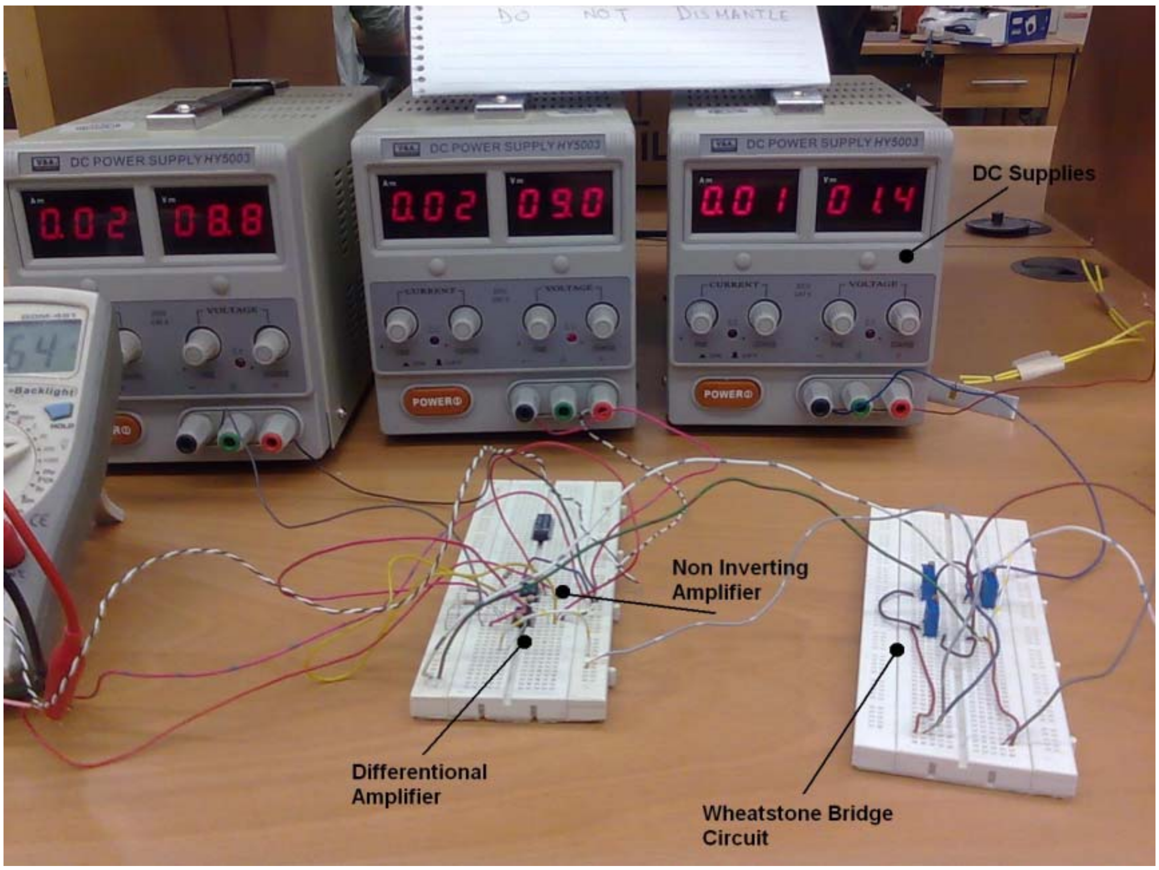


Differential amplifier



Non-inverting amplifier

$$V_{out} = V_{in}\left(1 + \frac{R_2}{R_1}\right) \qquad V_{out} = V_2 - V_1$$



Thermally induced apparent strain:

When strain gauge bonded with the base material Al, in our case, and temperature changes from room temperature to some other value, thermal stress acts on the base material and the material expands or contracts and

correspondingly the strain gauge wires become thinner or thicker. Furthermore, the change in temperature cause the change in resistance and the bridge circuit detects that change accordingly. This factor defines the thermally induced apparent strain and is free from any mechanical stresses.
Strain gauge sensitivity is calibrated with F_G and can be seen from the data sheet (F_G = 2 in our experiment).
Thermal output is caused by the following three factors;

i. Resistance change of resistive element of strain gauge due to temperature.

$$\Delta R/R = \alpha \, \Delta T \qquad \textbf{(a)}$$

ii. Thermal expansion of base material

$$\epsilon_b = \beta_b \, \Delta T \qquad \textbf{(b)}$$

iii. Thermal expansion of grid of strain gauge

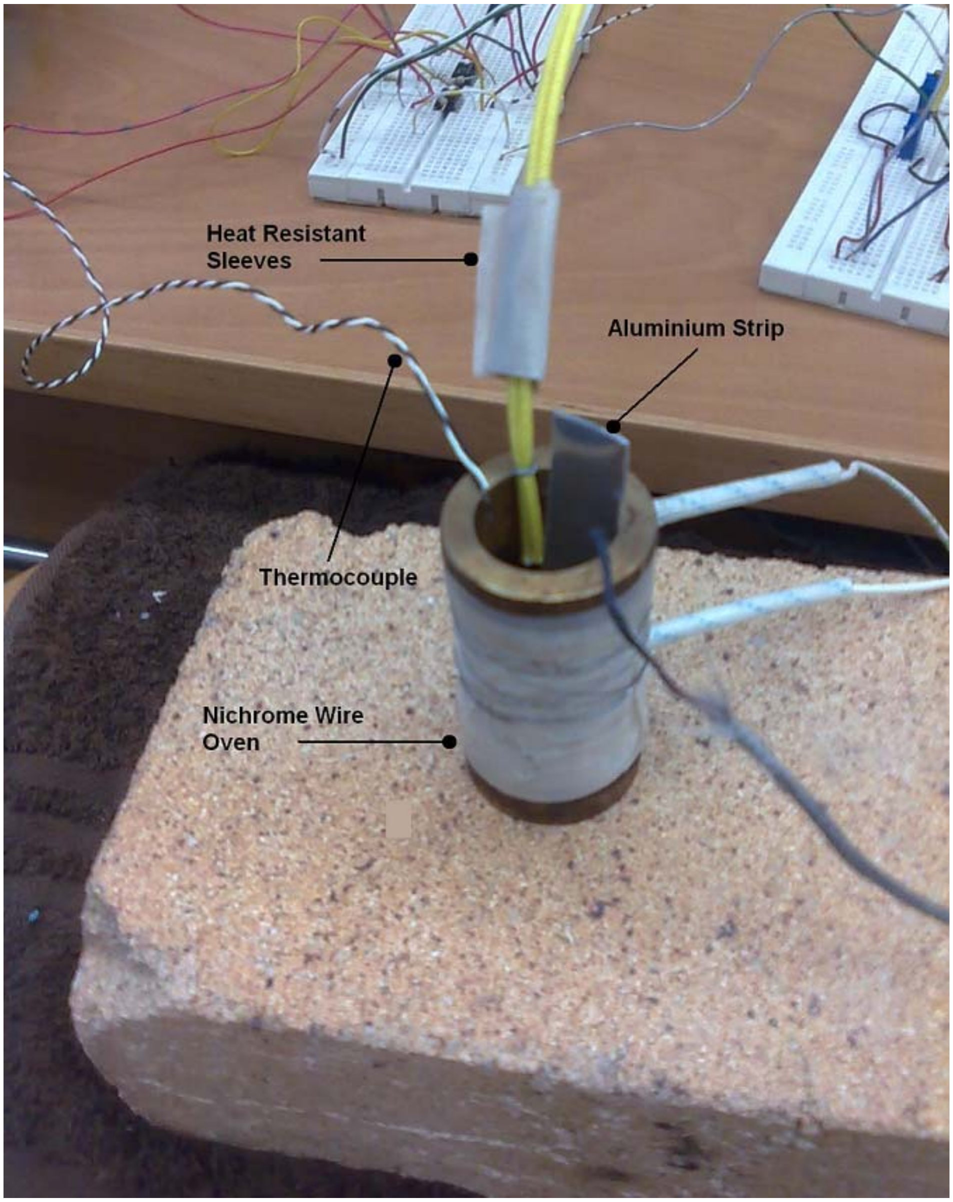
$$\epsilon_g = \Delta L/L = \beta_g \, \Delta T \qquad \textbf{(c)}$$

Each of two thermally induced resistance changes may be positive or negative with respect to temperature change. The net thermally induced apparent strain per degree rise in temperature can be computed from the above equations.

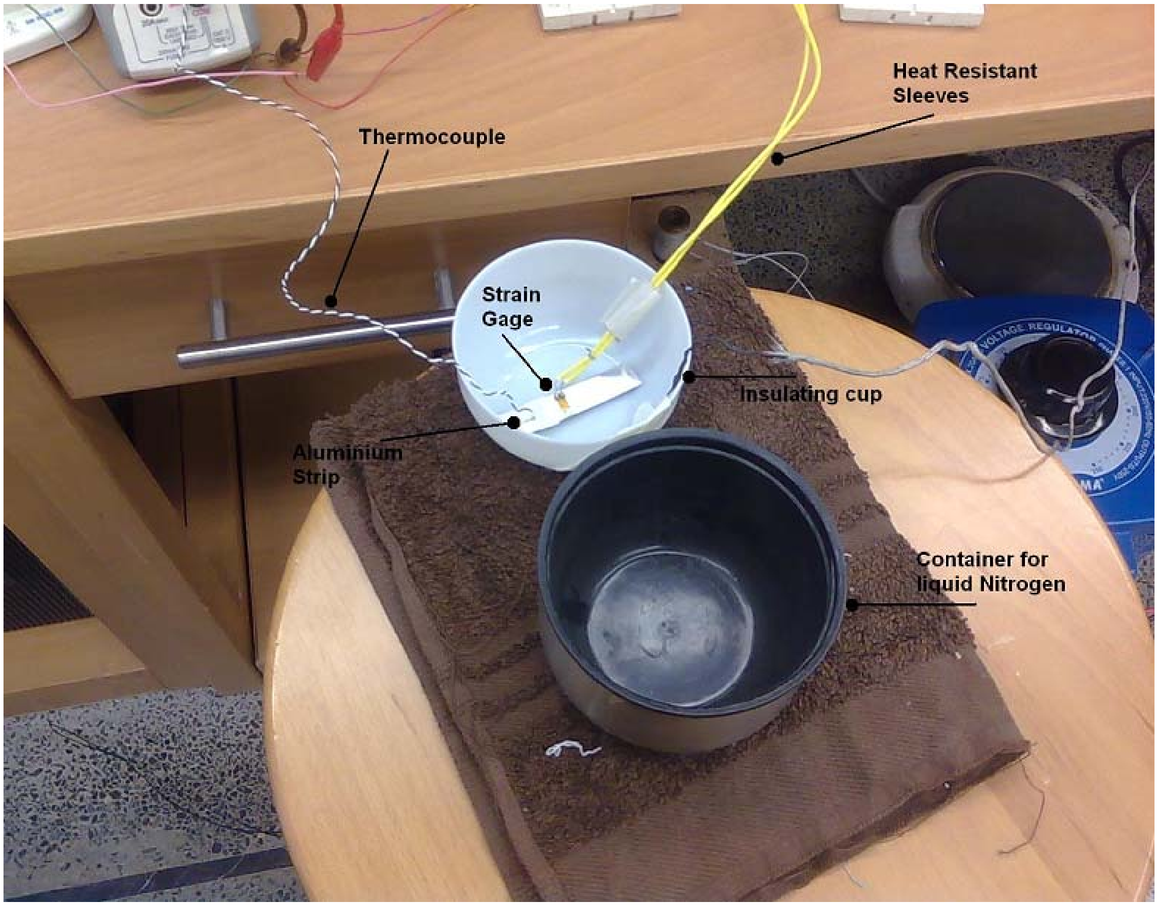
$$\epsilon_{thermal} = \alpha / F_G + \left| \beta s - \beta g \right| \qquad \textbf{(A)}$$

This shows that the thermally induced apparent strain gauge not only depend on strain gauge material but also on the base material to which the strain gauge is bonded.
For heating, the aluminium strip was placed in a hollow copper heater. The heater was wound with many turns of nichrome wire and insulation tape was wrapped around it, the heater was powered by a variac. We varied the temperature from room temperature to 200°C.

For cooling we used liquid nitrogen, we placed the strip in a plastic cup and dipped it in a container filled with liquid nitrogen. We varied the temperature from room temperature to -180°C.


Heat Resistant
Sleeves
Aluminium Strip
Thermocouple
Nichrome Wire
Oven

Copper Oven

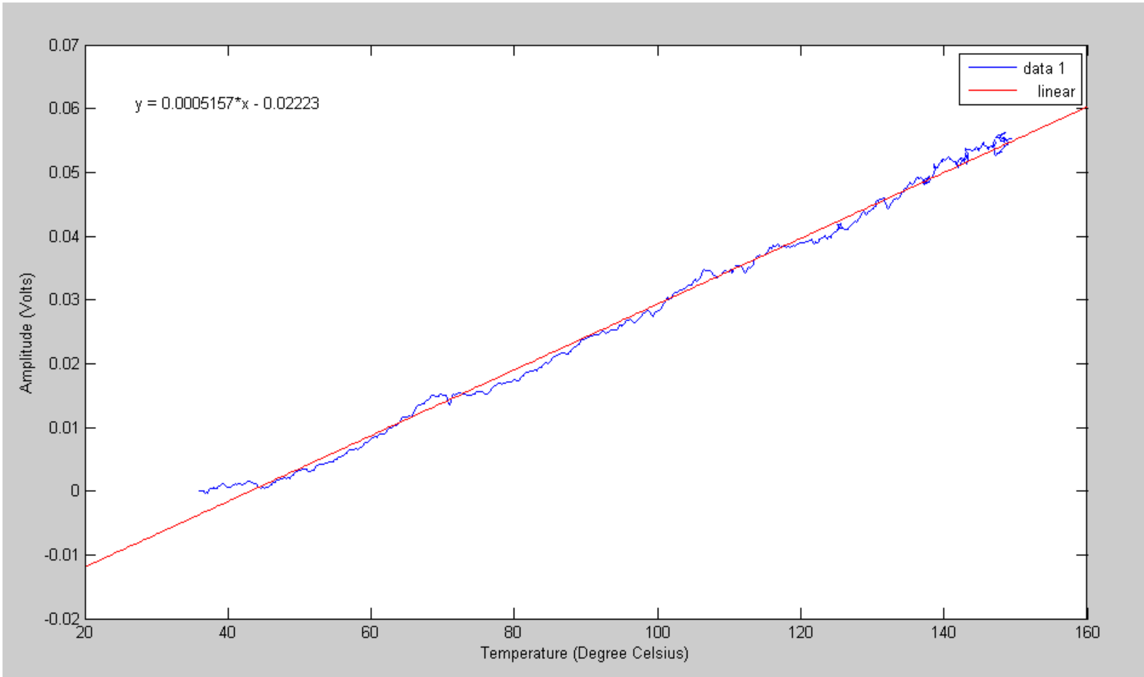


Cups for cooling with liquid nitrogen

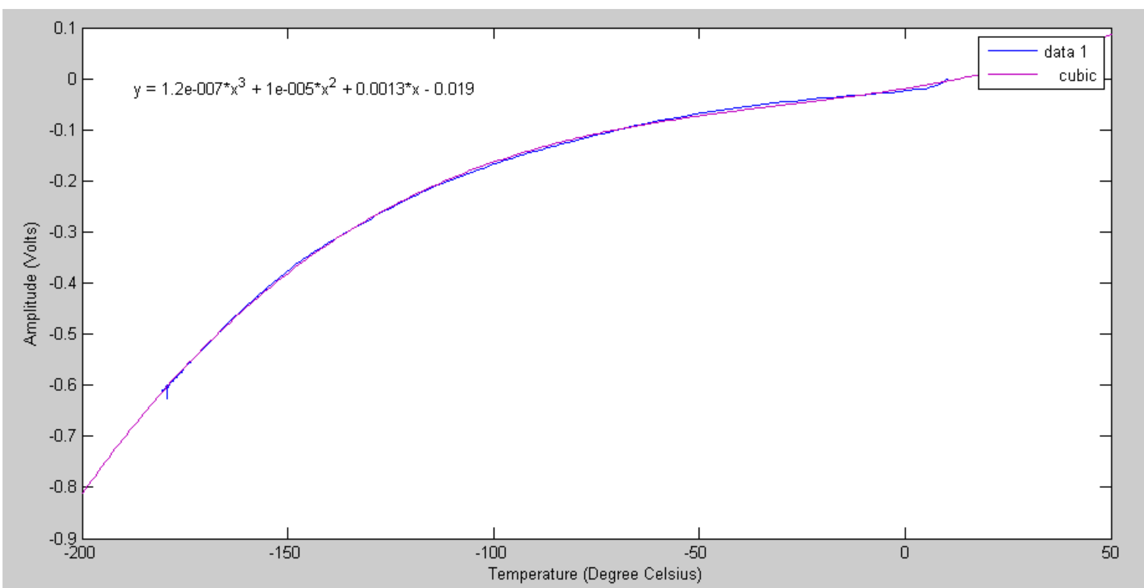
Data Acquisition

Data was acquired through a DAQ instrument (NI SCC - 68 Signal Conditioning Module), readings of voltage and temperature were sampled at a rate of hundred samples per second. The temperature was measured by a thermocouple which was taped to the aluminium strip and the voltages were measured after they were amplified a hundred times.

The data was conditioned and averaged in labview before it was stored. Graphs were plotted using Matlab. Here are the following graphs at high temperatures and low temperatures. The blue lines are the data lines and the red lines (smoother lines in black and white) represent curve fitting.



Change in Strain at High temperatures



Change in Strain at Low temperatures

Results

Thermally induced apparent strain gauge plots shows that the strain gauges can be used to detect not only the mechanical stresses but also the thermal stresses and is useful in a variety of applications to measure the thermal conductivity of mixture of gasses. Without any mechanical stress applied on the base material the gauge responds only to thermal stress and resistance of strain gauge grid changes according to the temperature. With the increase in temperature there is a decrease in resistance of strain gauge and vice versa.

Gage factor is the proportionality factor between the relative change of the resistance of the gage and metal. The Change in resistance (R) is in proportion to the strain sensitivity (S) of the wire's resistance. When a strain is introduced, the strain sensitivity, which is also called the gage factor (F_G), is given by:

$$\mathbf{F_G = \Delta R/R / \varepsilon}$$

It is 2 for our strain gage at a temperature of 23°C.

It can be seen in the graphs that the change is linear in the service temperature range but there is a drastic change in voltage below the lower bound of the temperature range (Note that the scales of the two graphs is different by a factor of ten). There are few fluctuations in the graph at high temperature due to noise and low noise at lower temperature is observed. Ideally linear behavior is observed and is most suitable to detect the molecular level differences that become apparent in most of the mixture of gasses at low temperature.

We can measure small changes in temperature in the service range of the strain gage by comparing it to the graphs above but we would need to measure with great precision and with very sensitive measuring devices as for a change of about 200°C, there is only a change of less than 0.2V. So to accurately detect a change of 1 degree in temperature, we need to measure a change of 0.001V due to resistance.

Conclusion:

Reasonably simple circuit was made to measure the thermally induced apparent strain measurements with the help of strain gauge and data were recorded as an observed voltage change in the circuit in the lab view and plotted against the temperature. In the high temperature range linear plots were obtained for the temperature and corresponding voltage to show the theoretical explanations between the temperature and resistance change of the strain gauge.

For the purpose of our ratio meter experiment in which we have very low temperatures, the gage factor and the strain do not vary linearly with temperature but we can still match them with the non linear graph and determine temperature. Here the change in voltage is greater for a change in temperature. For a change of 100°C, there is a change of 0.5V. The change is 0.005V/$^{\circ}$C.