STRAIN GAUGE MEASUREMENTS

1. OBJECTS

→ The object of this experiment is to calculate the stresses generated in a machine element when a force is applied. Sometimes due to the complexity of the machine element theoretical calculation of stresses are impossible, then experimental measurements are very valuable.

2. STRAIN GAUGE

When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur. For a uniform distribution of internal resisting forces, stress can be calculated (Figure 1) by dividing the force (F) applied by the unit area (A):

$$\rightarrow \text{Stress } (\sigma) = \frac{F}{A} \qquad (1)$$

Strain is defined as the amount of deformation per unit length of an object when a load is applied. Strain is calculated by dividing the total deformation of the original length by the original length (L):

$$\rightarrow \text{Strain } (\varepsilon) = \frac{\Delta L}{L} \qquad (2)$$

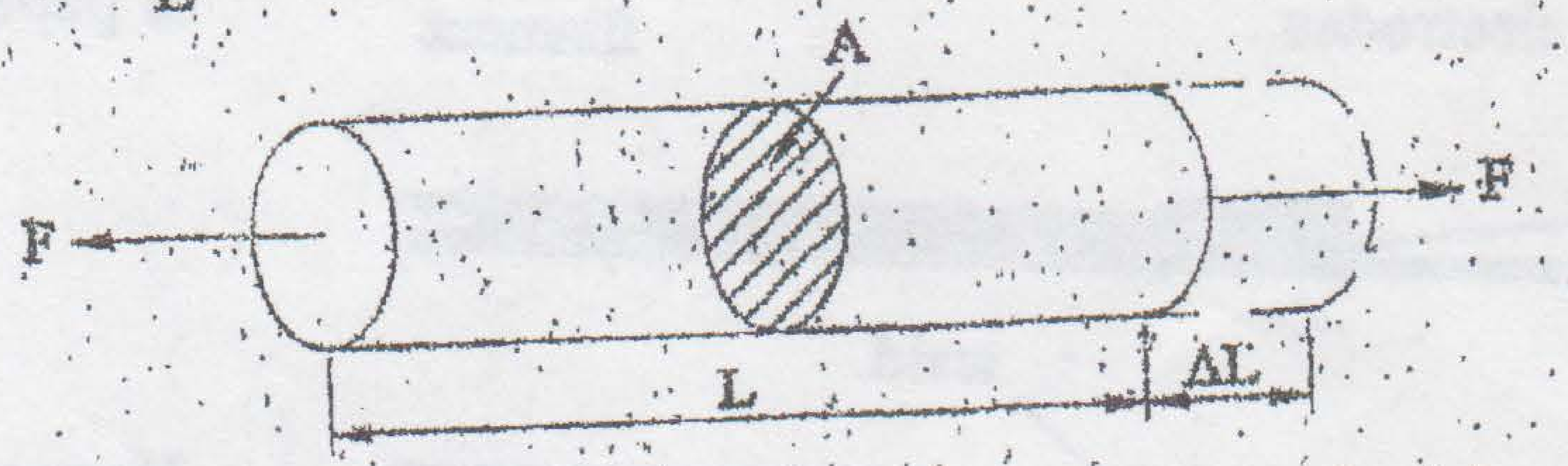

Figure 1. Definitions of Stress & Strain

→ Strain gauges are used to measure strains at a point. But by using strain gauges (length and width) to measure strains at a point without any error is impossible. To minimize this error various types of strains gauges developed. In these types of strain gauges, electrical resistance strain gauges are the most accurate ones. In this experiment, this type of strain gauge will be used and explained.

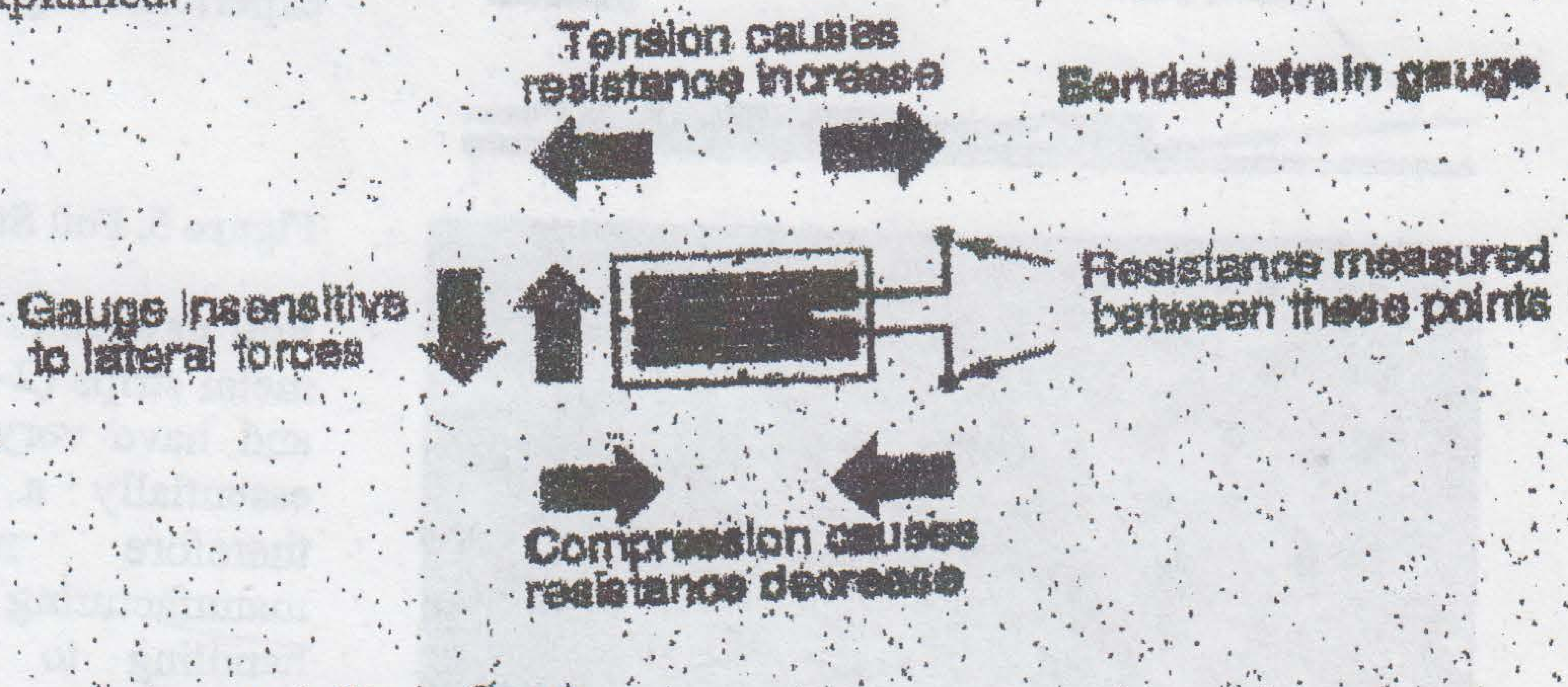

Figure 2. A Strain Gauge

A variable resistance strain gauge is a device whose electrical resistance changes in proportion to the strain to which it is subjected. In the case of bonded resistance-type strain gauge, the resistive element consists of a length of line metal wire, a metal foil, or a whisker of semi-conductive material. To reduce the length of the gauge while its sensitivity is retained, the wire, or foil, is usually formed in a grid pattern. The resistive element is fixed to suitable base, usually paper, plastic or ceramic. For use, the gauge is bonded to the point at which strain to be measured, or the base may be stripped away and the resistive element placed directly in a bonding agent at the point where the strain is to be measured.

Typical values for strain are less than 0.005 mm/mm and are often expressed in micro-strain units:

Micro-strain = Strainx10^6

Strain may be compressive or tensile and is typically measured by strain gages (Figure 2).

Wire gauges can be divided into two types: *flat wound* (Figure 3) and *wrap around* (Figure 4).

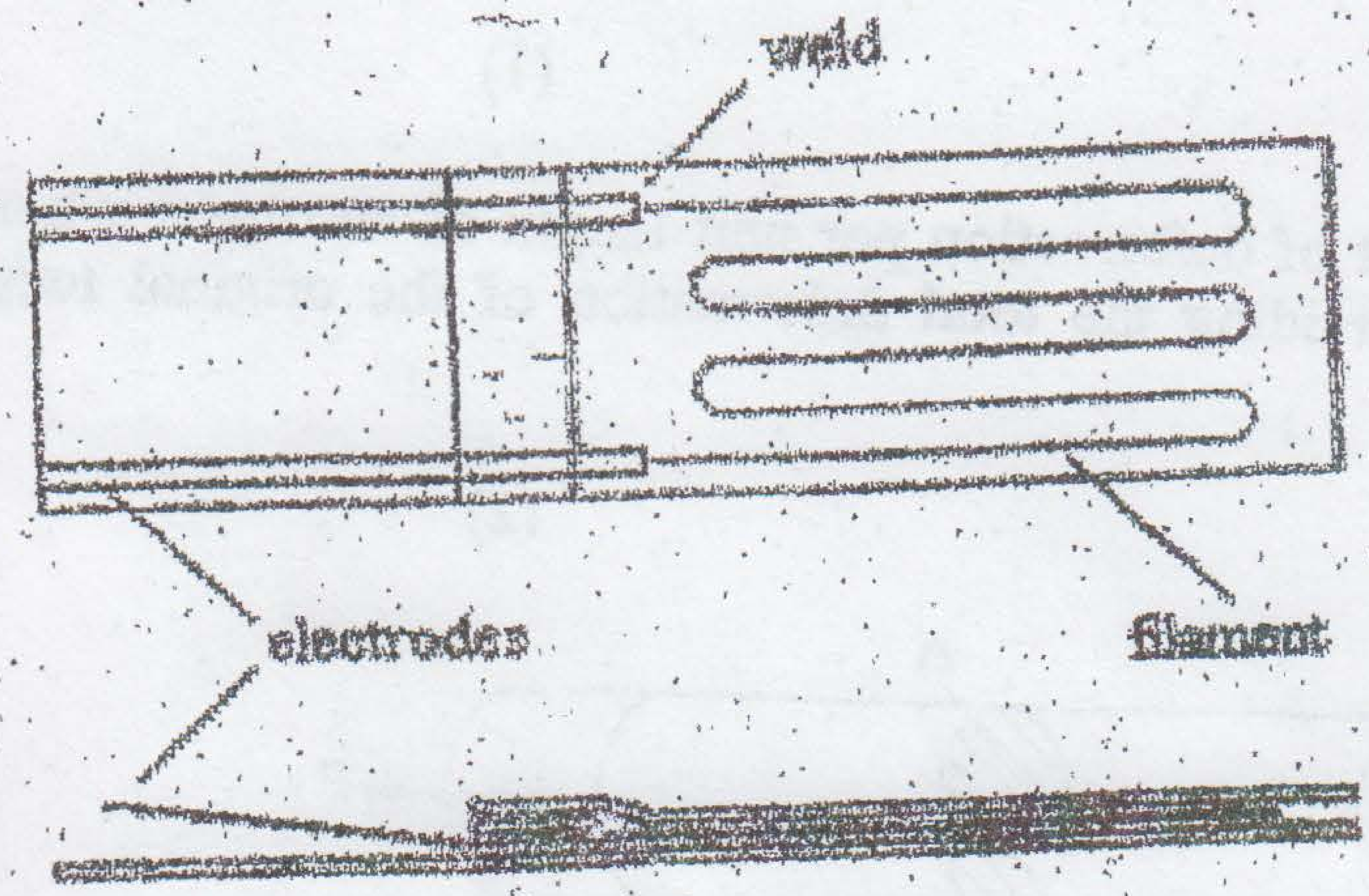

Figure 3. Flat wound strain gauge.

In flat wound gauges, the filament wire is zigzagged between two pieces of paper.

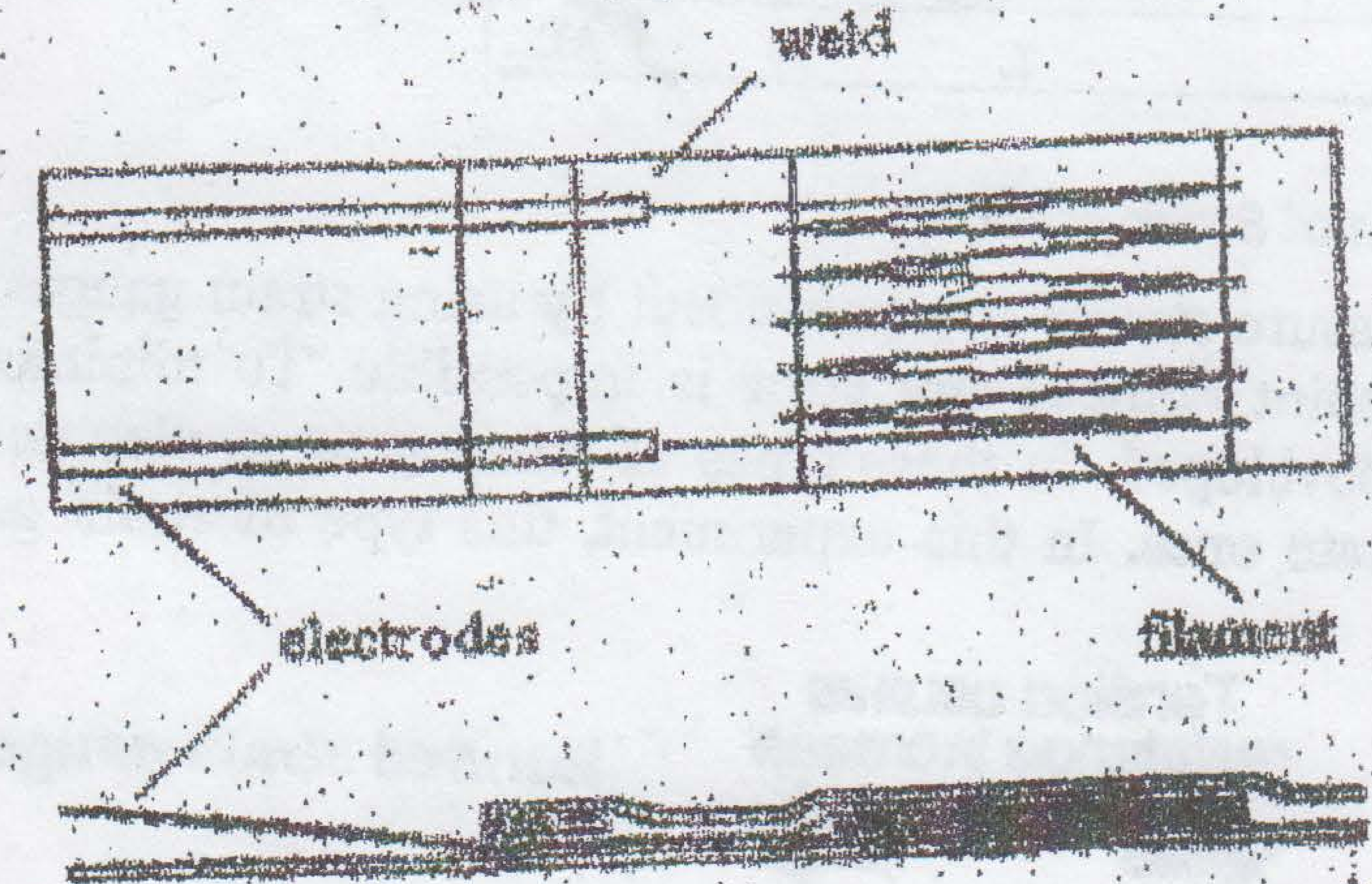

Figure 4. Wrap around strain gauge.

With wrap around gauges, the wire is wrapped around a paper support. The advantage of this is the possibility of smaller grid dimensions; the disadvantage is that they do experience higher levels of creep.

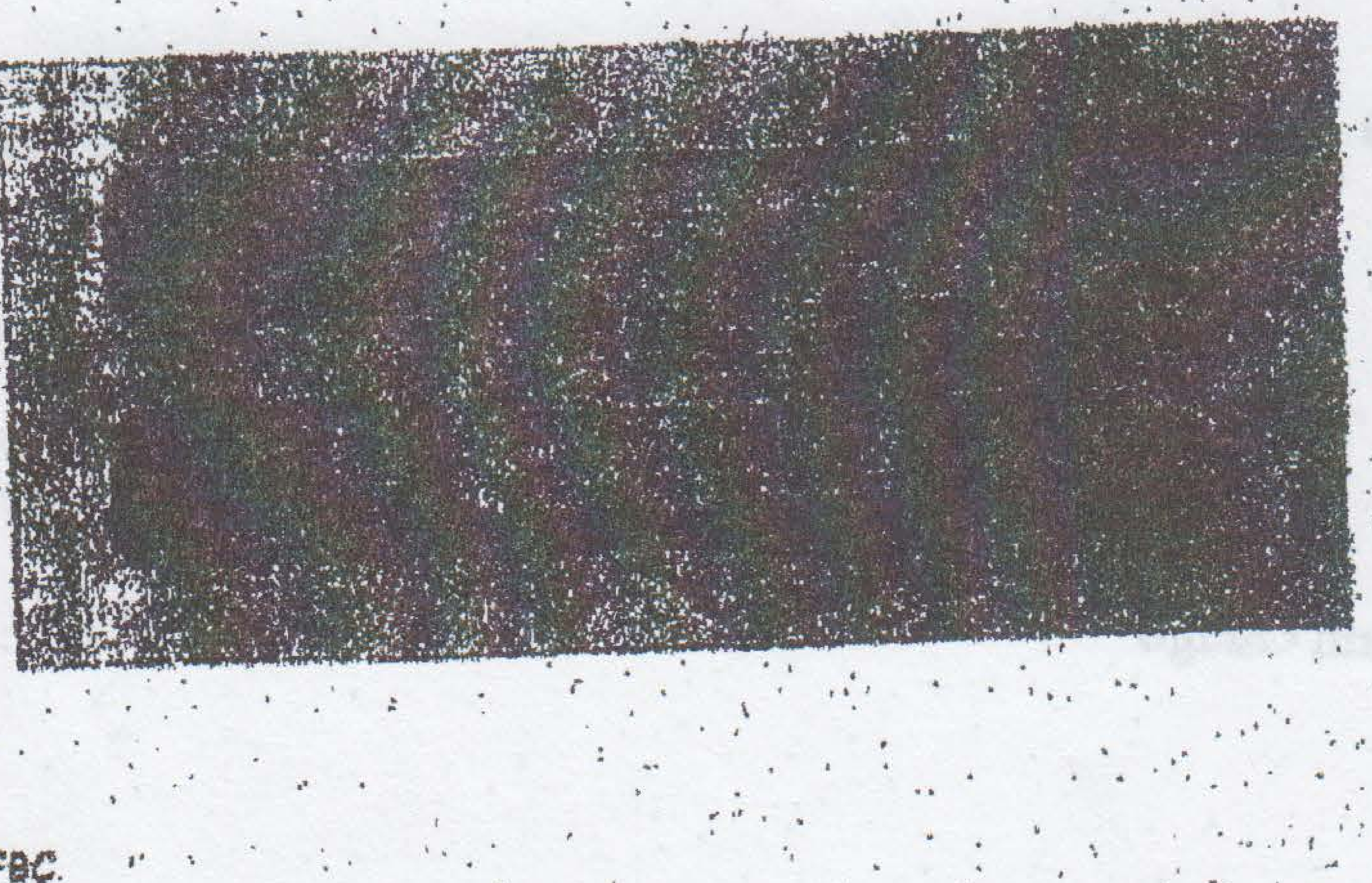

Figure 5. Foil Strain Gauge

Foil gauges are made from very thin metal strips (2-10 micrometers thick), and have very fine grids. They are essentially a printed circuit, and therefore require the best manufacturing techniques and careful handling to ensure good quality measurements.

Strain gauge was first discovered by Lord Kelvin in 1856 that the electrical resistance of metals is sensitive to strain. Originally, strain gages were made of wire and, in fact, wire strain gages are still in use under special circumstances. However, today foil strain gages are most widely used. The strain-sensing region of the strain gage is called the "gage grid". The grid is etched from a thin metallic foil. The orientation of the grid defines the strain-sensing axis of the strain gage. Electrical connections are made by soldering lead wires to the strain gage "solder tabs". The entire strain gage is bonded to a thin polymeric backing which helps protect and support the delicate metal foil.

Foil strain gages are available in literally hundreds of shapes and sizes. The strain gage shown is called a **"uniaxial strain gage"**. Other common strain gage configurations are:

Biaxial strain gages, which consist of two individual strain gage elements, oriented precisely 90° apart, allowing strain measurements in two orthogonal directions.

Rectangular, three element strain gage rosettes which consist of three individual strain gage elements oriented precisely 45° apart, allowing the resolution of principal strains and principal directions regardless of the orientation of the rosette or the applied stress/strain.

Delta, three-element strain gage rosettes which consist of three individual strain gage elements oriented precisely 60° apart, allowing the resolution of principal strains and principal directions regardless of the orientation of the rosette or the applied stress/strain.

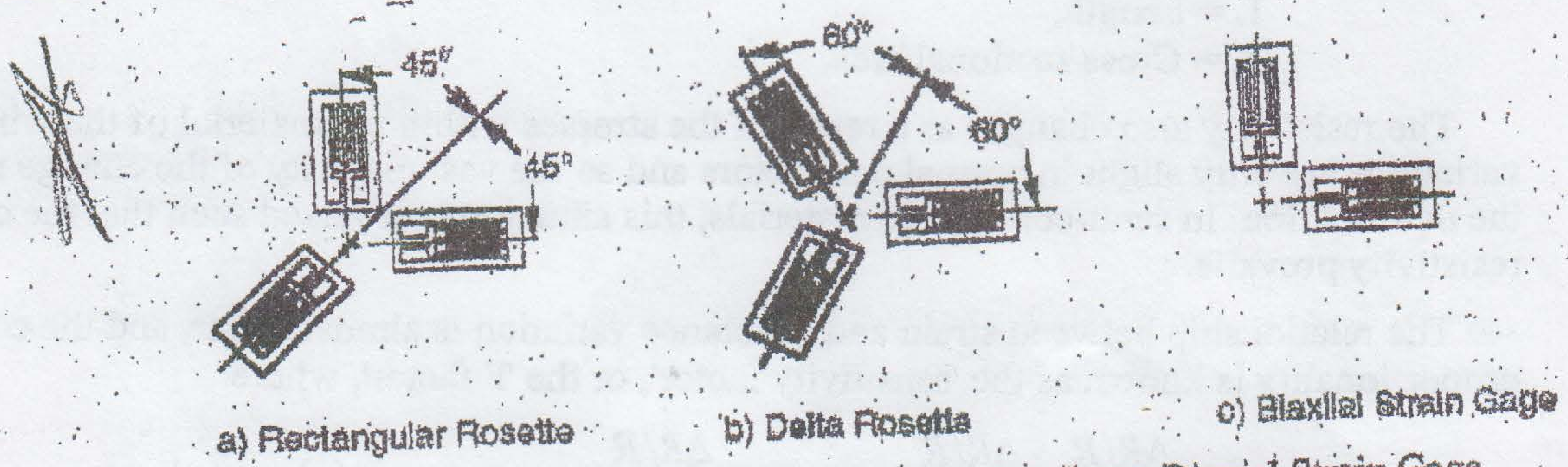

Figure 6. Rectangular and Delta Rosettes as well as a Biaxial Strain Gage

2.1.GAUGE CONSTRUCTION

Construction of electrical resistance strain gauges involves bringing together the optimum combination of electrical resistance material and backing plate.

For a good strain gauge, some of the most important features are listed below:

- Small size and mass,
- Ease of production over a range of sizes,
- Robustness,
- Good stability, repeatability and linearity over large strain range,
- Good sensitivity
- Freedom from (or ability to compensate for) temperature effects and other environmental conditions,
- Suitability for static and dynamic measurements and remote recording
- Low cost

2.2.GAUGE FACTOR

The use of strain gauges is based on the fact that the resistance of a conductor changes when the conductor is subjected to strain.

Figure 7 shows resistances wire in it's original state, and after subjected to a strain. The stretched wire has higher resistance, as it is longer and thinner.

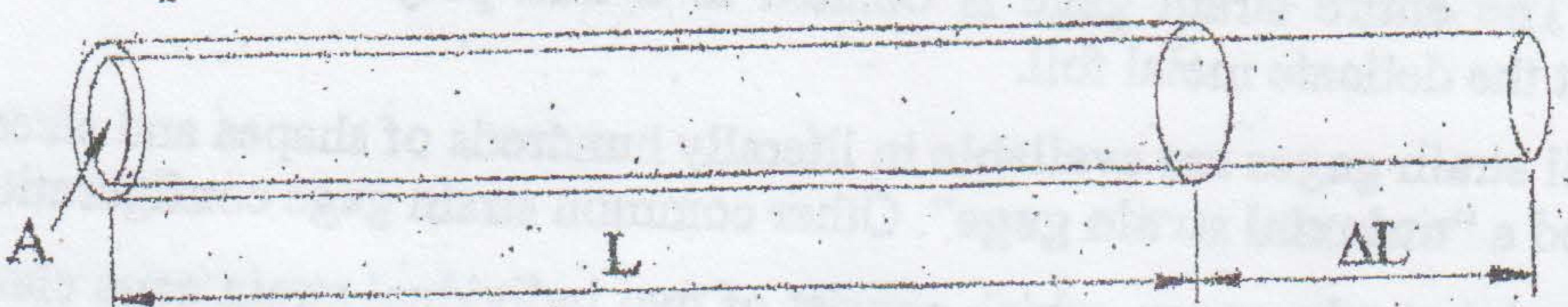

Figure 7. Resistance Wire

The electrical resistance of a conductor is given by:

$$R = \frac{\rho L}{A} \qquad (3)$$

Where: R = Resistance,
ρ = Resistivity,
L = Length,
A = Cross sectional area.

The resistivity also changes as a result of the stresses within the material of the wire, but these variations are only slight in normal conductors and so the vast majority of the change results from the deformation. In semi-conductive materials, this situation is reversed such that the change in resistivity prevails.

The relationship between strain and resistance variation is almost linear, and the constant of proportionality is known as the 'sensitivity factor', or the 'F factor', where:

$$F = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon} \Rightarrow \varepsilon = \frac{\Delta R/R}{F} \qquad (4)$$

Where: F = Sensitivity Factor (Gauge Factor),
R = Initial Resistance,
ΔR = Change in Resistance,
L = Initial Length,
ΔL = Change in length,
ε = Normal or Axial strain.

For a strain gauge, this constant is known as the 'strain sensitivity' of the gauge, or the 'gauge factor', and is given the symbol 'F'.

That is the gauge factor is a measure of the change in resistance per unit of original resistance that will occur per unit of strain applied. The gauge factor of a strain gage is an index of the strain sensitivity of the gauge. The higher the gauge factor, the more sensitive the gauge and the greater the electrical output for indication or recording purposes.

3. STRAIN GAUGE MEASUREMENT

An electrical resistance strain gauge in resistance due to applied strain according to Eqn. (4):

$$F = \frac{\Delta R / R}{\varepsilon} \Rightarrow \frac{\Delta R}{R} = F\varepsilon \qquad (5)$$

In order to measure strain with a bonded resistance strain gage, it must be connected to an electric circuit that is capable of measuring the minute changes in resistance $(\Delta R/R)$ corresponding to strain. Strain gage transducers usually employ four strain gage elements electrically connected to form a Wheatstone bridge circuit (Figure 8).

A Wheatstone bridge is a divided bridge circuit used for the measurement of static or dynamic electrical resistance. The output voltage of the Wheatstone bridge is expressed in millivolts output per volt input. The Wheatstone circuit is also well suited for temperature compensation. The Wheatsone bridge circuit consists of four "arms". Each arm contains a resistance (i.e. resistances, R_1, R_2, R_3 and R_4). An excitation voltage V_{ex} (typically 2 to 10 volts) is applied across junction A-C and a voltmeter is used to measure the resulting potential across junctions B-D (voltage ΔE).

$$\Delta E = V_{ex} \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_2)(R_3 + R_4)} \qquad (6)$$

From this equation, it is apparent that when $R_1/R_2 = R_4/R_3$, the voltage output ΔE will be zero. Under these conditions, the bridge is said to be balanced. Any change in resistance in any arm of the bridge will result in a nonzero output voltage.

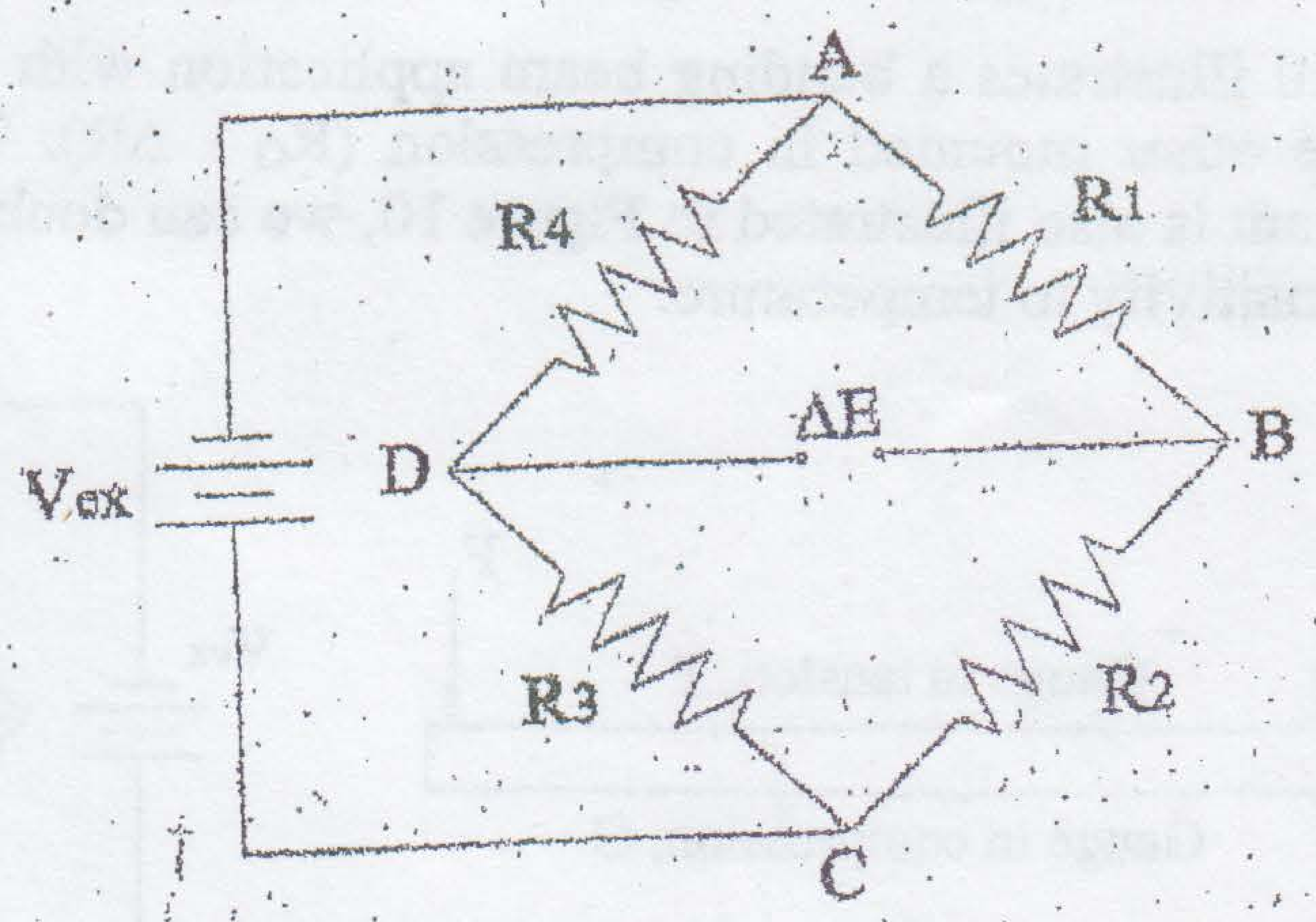

Figure 8. Wheatson Bridge

Therefore, if we replace R_1 in Figure 8 with an active strain gauge (i.e., $R_1=R_g$), and the other three resistances are precision resistors equal to the nominal resistance of R_g (i.e., $R_2=R_3=R_4$). If the strain gauge experiences a strain, the strain gauge resistance changes, causing the bridge to become unbalanced (Fig. 9.a.). The resulting voltage, ΔE is given by:

$$\Delta E = \frac{V_{ex}}{4}\left[\frac{\Delta R_g}{R_g}\right] \qquad (7)$$

Combining Eqs. 5 and 7 yields:

$$\varepsilon = \frac{4}{F}\left[\frac{\Delta E}{V_{ex}}\right] \qquad (8)$$

Equation 8 is an important result. It shows that the strain in the strain gage, ε, is related to the quantities, F, ΔE and V_{ex}. Generally though, Eq. 8 is not applied directly, instead, strain gauge amplifiers, which have been calibrated according to Eq. 8, are used to provide a direct readout of strain.

The sensitivity of the bridge to strain can be doubled by making both gauges active in a half-bridge configuration shown in Fig. 9.b.

We can further increase the sensitivity of the circuit by making all four of the arms of the bridge active strain gauges in a full-bridge configuration. The full-bridge circuit is shown in Fig. 9.c.

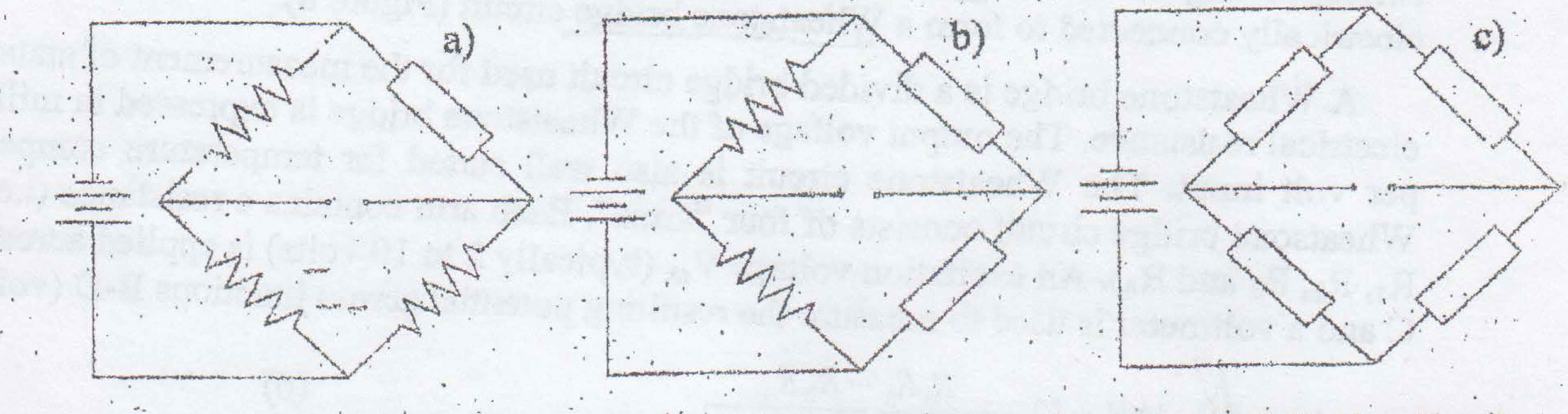

Figure 9. a) Quarter-Bridge Circuit b) Half-Bridge Circuit c) Full- Bridge Circuit

4. MEASUREMENT OF BENDING STRAIN

Consider measuring the bending strain in a cantilever

Figure 10 illustrates a bending beam application with one bridge mounted in tension ($R_G + \Delta R$) and the other mounted in compression ($R_G - \Delta R$). This half-bridge configuration, whose circuit diagram is also illustrated in Figure 10, we can double the sensitivity to bending strain *and* eliminate sensitivity to temperature.

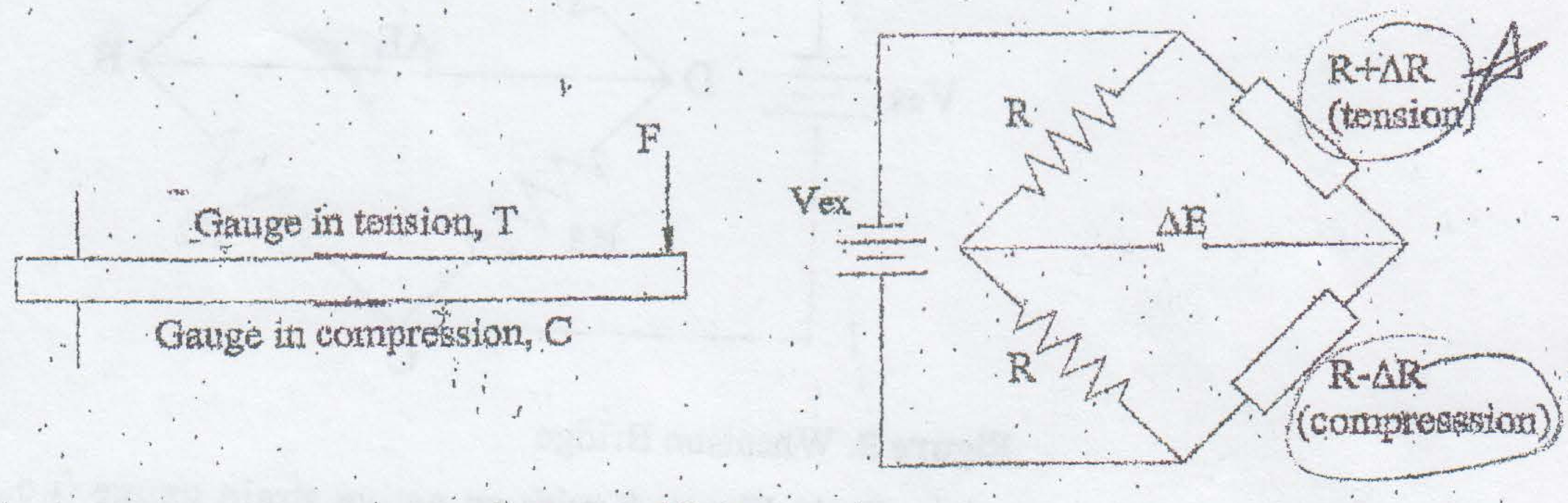

Figure 10. Measurement of a bending strain.

We can demonstrate that the output is given by:

$$\Delta E = \frac{V_{ex}}{2}\left[\frac{\Delta R}{R}\right] \qquad (9)$$

(i.e. the output is double that from a quarter bridge circuit).

Further you can demonstrate that if the resistance of both gauges increases (due to temperature or axial strain) then the output voltage remains unaffected (try it by putting the resistance of gauge C as R+ΔR).

Calculation:

a. Calculate theoretical strain value for each weight.
b. Draw strain versus stress graphs for broth, Theoretical and experimental strain values.
c. Using this graphs find angle of string with horizontal.

$E = 2.11*10^6\ kg/cm^2$

Experimental set-up

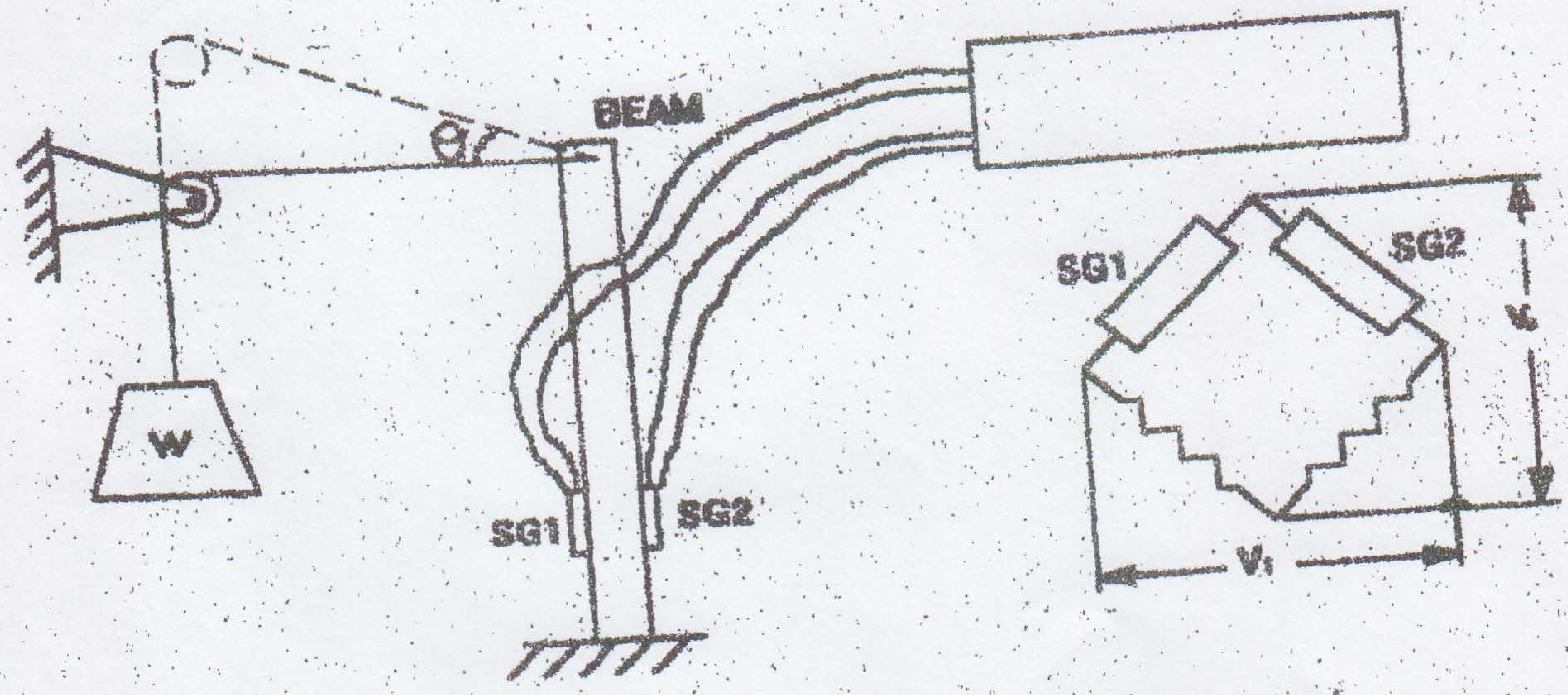

FIGURE 7

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