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DESIGN AND CONSTRUCTION OF AN ABSOLUTE GRAVITY METER

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ABSTRACT

An absolute gravimeter which has been designed and constructed consists of a timing circuit which measures the time a body takes to fall between two points separated by a known distance. The time of fall and the known distance are used to calculate the acceleration of gravity at the point of experimentation. Test measurements around some points where gravity acceleration is known shows that the gravimeter gives reliable results.

KEY WORDS: Absolute gravimeter, timing circuit, acceleration of gravity, reliable results.

INTRODUCTION

There are two types of gravity measurements in gravity survey, the absolute gravity value at a point, and the difference in gravity at a point relative to another. Each type of measurement gives different information. The absolute gravity field is used to determine the size and mass of the earth, it is also used in the study of artificial satellites moving under the gravitational attraction of the Earth (Cook, 1973), the difference in gravity field at a point relative to another is used for mineral or near surface geological survey (Press and Siever, 1978). Whereas measurement of relative gravity values in practice is simple because portable instruments called gravimeters (Keary and Books, 1993) are available for the purpose, measurement of the absolute gravity field (g) is made classically by experiment using either pendulums or falling bodies (Keary and Books, 1993). The principle is basically to attempt to measure times and lengths accurately from which the gravity field g is calculated using relevant equation.

Before 1950, all measurements of g were based on the period of oscillation of a simple pendulum (Garland, 1965). After 1950, however, other methods of measurements were introduced which include: the compound pendulum method, coupled pendulum method, interferometer method and falling body method. The most recent approach is the measurement by falling body method. In this method, it must be possible to measure very small times accurately. These times of fall of the body are measured electronically. Because of the difficulty of starting the measurement at the exact time that the body begins to fall, timing usually begins after the object has fallen several centimeters from its rest position.

DESIGN SPECIFICATION OF THE ABSOLUTE GRAVITY METER

The technical design of the absolute gravity meter is subdivided into two major sections: the mechanical section and the electrical section. The electrical section is further subdivided into three sections: the switching circuit, the oscillator and the counting circuit.

(a) **The switching circuit**

For the gravimeter to function properly, the following conditions must be met.

(i) The base voltage of the silicon transistors Q_1 and Q_2 in figure 1 should be 0.7V for saturation (Albert, 1984). If the sum of R_1 and R_2 is denoted be R_A and the resistance of the light dependent resistor is denoted by R_B. Then R_A and R_B have to be chosen, such that the base voltage in the silicon transistor, Q_1 will be 0.7V. The values for R_A and R_B are worked out as follows:-

Since the resistors R_A and R_B are connected in parallel, let the total resistance of R_A and R_B be denoted by R_T. That means:

$$\frac{1}{R_T} = \frac{1}{R_A} + \frac{1}{R_B} \quad \ldots\ldots\ldots 1$$

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$$\text{or} \quad R_T = \frac{R_A R_B}{R_A + R_B} \tag{2}$$

If the voltage across R_T is V_T, then using the potential divider rule:

$$V_T = \frac{R_B}{R_A + R_B} V_{CC} \tag{3}$$

$$\Rightarrow \quad \frac{V_T}{V_{CC}} = \frac{R_B}{R_A + R_B} \tag{4}$$

$$\text{or} \quad \frac{0.7V}{5V} = \frac{R_B}{R_A + R_B} \tag{5}$$

$$\text{i.e.} \quad 7R_A + 7R_B = 50R_B \tag{6}$$

$$\text{or} \quad 7R_A = 50R_B - 7R_B \tag{7}$$

$$\text{or} \quad 7R_A = 43R_B \tag{8}$$

$$\text{or} \quad \frac{R_B}{R_A} = \frac{7}{43} \tag{9}$$

Thus the ratio of R_A to R_B is approximately 6:1

$$\text{i.e.} \quad R_A : R_B \approx 6:1 \tag{10}$$

(ii) The value of the load R_5 also in figure 1 is chosen as follows:

In darkness,

$$I_b = \frac{V_{CC} - V_B}{R_1 + R_2} = \frac{5.0 - 0.7}{R_1 + R_2} \tag{11}$$

But $R_1 + R_2 = 150\ \text{K}\,\Omega$

$$\Rightarrow \quad I_b = \frac{5.0 - 0.7}{150 \times 10^3} = 28.66\mu A \tag{12}$$

At saturation, the following equation holds,

$$\frac{V_{CC} - V_{CE}}{R_5} >> hf_e I_b \tag{13}$$

but hf_e = gain of the transistor = 200 (R.S. Components, 1992)

And V_{CE} = 0.2 (also R. S. Components, 1992)

$$\Rightarrow \therefore \frac{5-0.2}{R_5} >> 200 \times 28.66 \times 10^{-6} \quad \ldots\ldots\ldots\ldots\ldots\ldots 14$$

$$\text{i.e.} \quad R_5 << \frac{5.0-0.2}{200 \times 28.66 \times 10^{-6}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 15$$

$$\text{or} \quad R_5 << 837.4\Omega \quad \ldots\ldots\ldots\ldots\ldots\ldots 16$$

Therefore the load R_5 was chosen to be 800Ω

(b) **The astable multi-vibrator (oscillator)**

In the design of the astable multi-vibrator, the frequency of operation is given by the fomular: (Fredrick, 1981).

$$f = \frac{1}{R} = \frac{1.46}{(R_A + 2R_B)C} \quad \ldots\ldots\ldots\ldots\ldots\ldots 17$$

The variable resistor R_B can be used to vary the frequency of operation of the oscillator. A more symmetrical output waveform can be achieved if R_B is approximately five times greater than R_A (Fredrick, 1981)

(c) **The counting circuit.**

The counter is an electronic circuit, that can count the number of pulses applied to its input terminals. It is a J – K flip – flop. That is, each stage must change state before the following stage can do so. The counting circuit is constructed using decade counters which are integrated circuits with no. 7490, B – C – D – to – 7. segment decorder/driver, which are integrated circuits with no. 7448, and a number of 7 – segment LED display.

Selection of Components

In the design of the meter itself, we note that the light dependent resistors LDR's have a light resistance of 700Ω and a dark resistance in mega ohms (R.S. Components, 1992). The value of the dark resistance depends on the degree of darkness. The resistance of the LDR's were measured in the tube (partial darkness) and found to be about 25kΩ. We therefore take the resistance of the light sensor in partial darkness, that is 25kΩ as the fixed value. Since the ratio of the resistances should be about 6:1 (see equation 10,) we therefore chose the sums $R_1 + R_2$ and $R_3 + R_4$ in figure 1 to be 150kΩ each. The resistors R_2 and R_3 are variable resistors used for fine-tuning. (See figure 1). The load, as earlier explained was chosen to be 800kΩ.

OPERATION OF THE GRAVITY METER

The gravity meter is in normal condition when light falls on both light sensors. At this state, the entire system will not conduct as transistors Q1 and Q2 will be reverse biased. As the copper object falls across the light sensor 1, it obstructs light from reaching the sensor. (See figure 2). The resistance of the sensor increases to about 25kΩ, since the sum of R_1 and R_2 is 150kΩ. This process forward biases transistor Q_1, which will conduct heavily. When Q_1 conducts heavily, it triggers the clock and changes the state of the output of Q in the j – k flip – flop from logical O to logical 1. The system remains at that state until the falling object falls across the second light dependent resistor. When this happened, Q_2 will conduct heavily; this action returns the bistable multivibrator to logical O (R. S. Components, 1992)

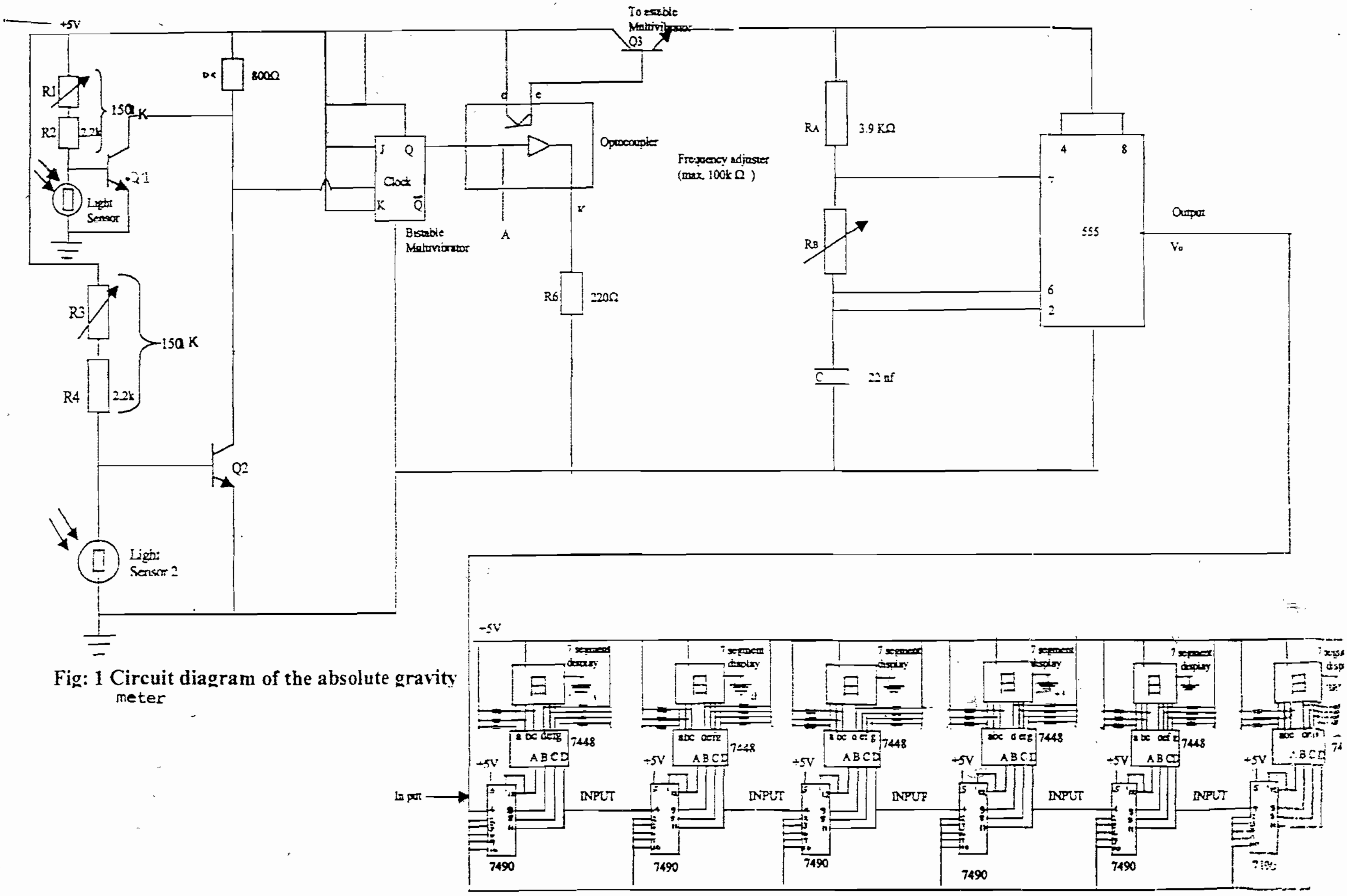

Fig: 1 Circuit diagram of the absolute gravity meter

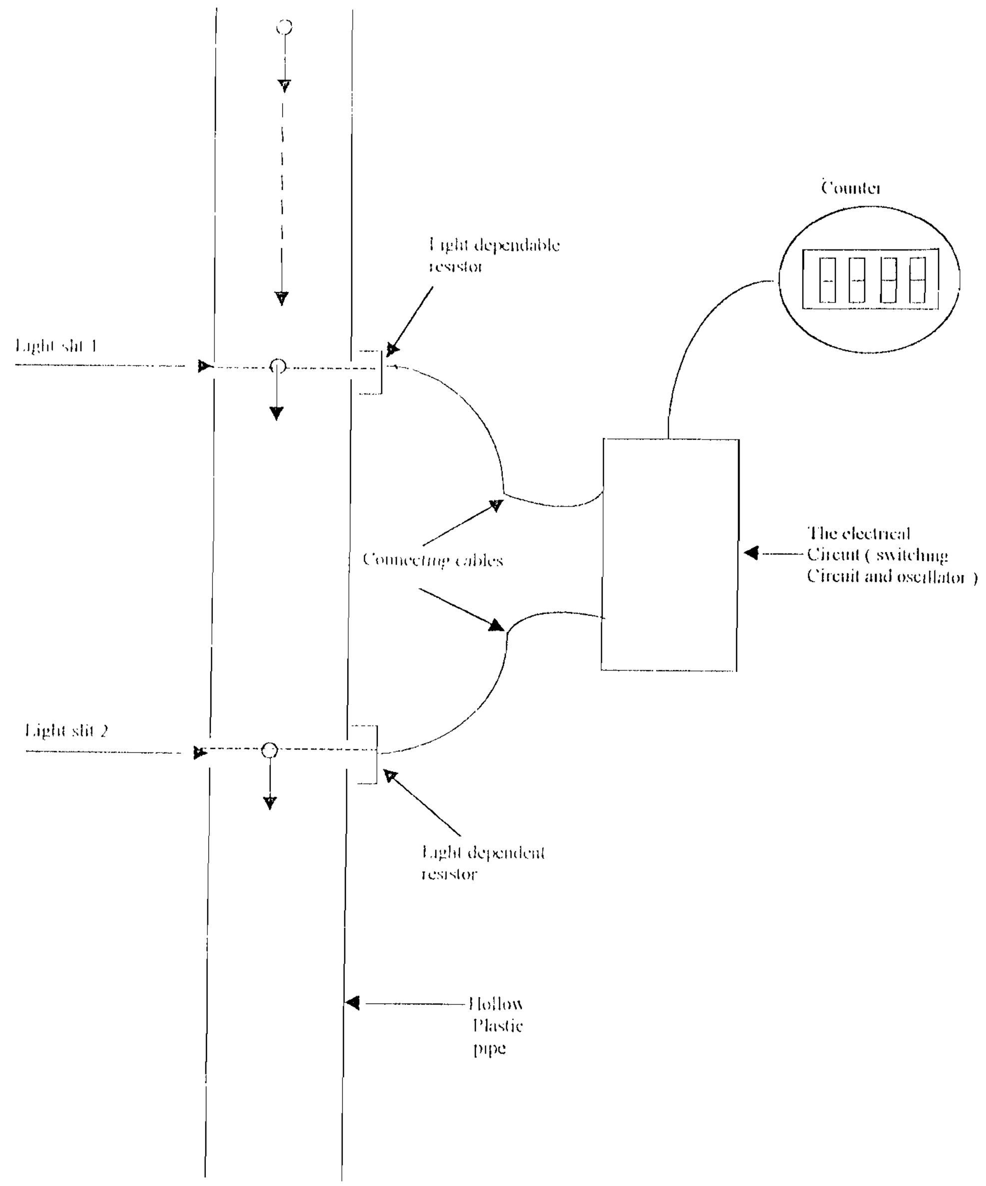

Figure 2 ; Schematic diagram of the absolute gravity meter

Q_3 acts as the switch, when the bistable multivibrator is at logical 1, Q_3 is forward biased and will conduct heavily. This action makes most of the voltage (+5V) to pass straight to the astable multivibrator. This supplies the power necessary to operate the multivibrator which then generates square waves which are counted by the counter. When the object falls past the light sensor 1, Q, will be reverse biased. This stops Q, from conducting, consequently, Q_3 will also be reverse biased and most of the voltage (+5V) will no longer pass to the astable multivibrator. But, the trigger has already been initiated; so, the astable multivibrator continues to run freely producing the square waves.

When the falling object passes the light sensor 2, the process that took place when it passed through light sensor 1 is repeated. The power supplied in this case is used to stop the production of the square waves. The waves, which are produced, are fed to the counter through pin 14 of a decade counter (7490). This decade counter is a divide-by-ten counter. After counting, the outputs A, B, C, D, it goes out through pins 12, 9, 8, and 11 respectively. The outputs are fed to a B-C-D- to –7 – segment decoder/driver. This integrated circuit accepts binary coded decimal signal at it's A, B, C, and D input to give out 7 – segment LED display.

The output D from the first decade counter is used as input to the second decade counter. The process that took place in the first stage from, the first decade counter to the B-C-D- to –7 – segment decoder/driver and finally to the 7 – segment display is repeated, and the next count displayed. This continues for the rest of the four-decade counters, displaying a total of six digits.

The counter counts the number of pulses produced, when the object falls between given known points. Knowing the frequency of the signal generated, the period T of the wave can be calculated from the formula T = 1/f. This period T is the time taken for the wave to make a complete oscillation. Since the numbers of pulses are counter, the time taken between the fall is given by multiplying the periodic time T by the number displayed by the 7 – segment display. Thus

$$T = 1/f$$

Time in seconds = T x number of count.

TEST MEASUREMENT OF ABSOLUTE GRAVITY VALUES IN CALABAR.

The first test measurement station using the designed system is located at the Bassey Duke Effigy in Calabar. This station was chosen because some previous measurements of the absolute gravity had been made in that location (Osazuwa, 1985). The objective of making the test measurement here was to compare the measurement made with the designed system to those made with a conventional gravimeter. The average gravity value at the Bassey Duke Effigy as obtained by previous measurements is 9.7807075 m/s^2 (Osazuwa, 1985).

In the recent measurements, the times of fall are as shown in tables 1 and 2. For each height, four measurements of the times of fall were made and the average of the four measurements gave the of the time of fall of the Copper mass.

TABLE 1 Time of fall for a height of 1.0 meter at Bassey duke Effigy.

Height(m)	Time of fall (s)
1.0	0.2146
1.0	0.2146
1.0	0.2146
1.0	0.2146

The average time of fall for 1.0m height is 0.2146 seconds.

TABLE 2: Time of fall for a height of 1.5 meter at Bassey Duke Effigy.

Height(m)	Time of fall (s)
1.5	0.2964
1.5	0.2965
1.5	0.2965
1.5	0.2964

The average time of fall for 1.5height is 0.2965 seconds.

The absolute gravity value at a place can be calculated using the following physical equation (Crummet, 1990).

$$g = 2\frac{\left(\dfrac{h_2 - h_1}{t_2 - t_1}\right)}{t_2 - t_1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 18$$

Where $h_1 = 1.0m$, $h_2 = 1.5m$, $t_1 = 0.21465$, $t_2 = 0.296455$

⇨ $g = 9.775026\ m/s^2$

Now recalling that the earlier value of the absolute gravity obtained at the Bassey Duke Effigy (Osazuwa, 1985) was 9.7807075 m/s^2, while the value obtained from this experiment is 9.775026 m/s^2. Both measurements differ by 0.0056815 m/s^2 One may attribute the difference to a number of factors associated principally with the new gravity meter used. These include:

1. The air friction in the tube which might not have allowed the body to fall as freely as it would, if it were in a vacuum.
2. There may also be some error arising from the size of the falling mass. It appears that a smaller mass would give a better result compared to a large one.

However, the percentage difference using the previous and present values can be determined as follows:

$$\text{Percentage error} = \frac{(\text{previous value of } g - \text{recent of } g) \times 100}{\text{Previous value of } g}$$

$$\text{i.e. percentage error in } g = \frac{9.7807075 - 9.775026 \times 100}{9.7807075}$$

$$= 0.058\%$$

i.e. percentage error for the measurement at Bassey Duke Effigy = + 0.058%

Assessing the newly constructed gravity meter against the conventional gravimeter, it appears that the constructed gravimeter gives an error of measurement of up to 0.058%. The percentage error is quite small, but the numerical value of the error is significant for a detailed geological survey.

The second gravity measurement is at Odukpani junction, where the highway from Calabar to Ugep branches to Uyo. At this station also similar experiments as in Bassey duke effigy were performed using the designed system, and the average values of the times of fall are as shown in table 3 and 4.

TABLE 3: Time of fall for a height of 1.0m at Odukpani junction.

Height(m)	Time of fall (s)
1.0	0.2147
1.0	0.2146
1.0	0.2146
1.0	0.2147

The average time of fall for 1.0m height is 0.21465 seconds.

TABLE 4: Time of fall for a height of 1.5m at Odukpani junction.

Height(m)	Time of fall (s)
1.5	0.2964
1.5	0.2963
1.5	0.2965
1.5	0.2964

Again for 1.5m the average time of fall is 0.2964.

Using the same equation 18 to determine g:

That gives:

$$g = 2\frac{\left(\frac{h_2 - h_1}{t_2 - t_1}\right)}{t_2 - t_1}$$

For h_1 = 1.0m, h_2 = 1.5m, t_1 = 0.21465s, t_2 = 0.2964s

That gives $g = 9.834421 \text{m/s}^2$

That last experimental station is located near the physics laboratory of the Polytechnic, Calabar The readings obtained here are shown in the tables 5 and 6

TABLE 5: Time of fall for a height of 1.0m at physics laboratory of the Polytechnic, Calabar.

Height(m)	Time of fall (s)
1.0	0.2146
1.0	0.2146
1.0	0.2147
1.0	0.2147

The average time of fall for a height of 1.0m is 0.21465s.

TABLE 6: Time of fall for a height of 1.5m at physics laboratory of the Polytechnic, Calabar.

Height(m)	Time of fall (s)
1.5	0.2964
1.5	0.2965
1.5	0.2965
1.5	0.2964

Here the average time of fall is 0.29645s

Again using the equation

i.e.

$$g = 2\,\frac{\left(\frac{h_2}{t_2} - \frac{h_1}{t_1}\right)}{t_2 - t_1}$$

, that gives:

$g = 9.807540/s^2$

CONCLUSION

In this work, an absolute gravity meter has been constructed using materials purchased in Nigeria. The measurements obtained at Bassey duke Effigy using the constructed meter are very close to those obtained with conventional gravimeters. The error in measurements using the meter which is quite small is about 0.058%. However, this is significant for detailed geological surveys. It is therefore not advisable to use this instrument to replace the conventional gravimeter in detailed geological studies. However, the instrument can at least be used for student's practical training where a conventional gravity meter is not available. It is hoped that in further work, one will explore the possibility of designing a vacuum enclosure for the falling body; that will certainly improve upon the measurement made with the instrument.

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