

# GRAVITATIONAL TORSION BALANCE

ORIGINAL MODELS  
*of the*  
BARON ROLAND EÖTVÖS GEOPHYSICAL INSTITUTE  
BUDAPEST, HUNGARY

*Made in the*  
FERDINAND SÜSS INSTITUTE FOR PRECISION  
MECHANICS AND OPTICS COMPANY, LTD.  
BUDAPEST, HUNGARY

*Exclusive American Representative*

DR. GEORGE STEINER  
1802 CALIFORNIA STREET  
HOUSTON, TEXAS

The following is a brief description of the Eotvos Torsion Balance.

The theory and use of the instruments are described in separate pamphlets, which are furnished with every Balance. These pamphlets are detailed in every point of view so that any scientifically trained man who follows the instructions will be able to operate a Torsion Balance.

The American Representative of the manufacturer will be glad to furnish any information desired.

G. S.

# GRAVITATIONAL TORSION BALANCE

THE eminent Hungarian physicist Baron Roland Eotvos, celebrated Professor of the University of Budapest, began his important gravitational researches in the early eighties of the last century, and improved his method to a high degree by the strenuous work of four decades. The fundamental principle of the Eotvos gravitational method consists in the application of the Torsion Balance for the determination of the variations of gravity in space. For this he worked out a precise physical and mathematical theory of his method, and likewise constructed for the measurements a suitable and almost incredibly sensitive instrument, the Torsion Balance.

The first instruments of Eotvos were made in the *Ferdinand Suss Institute for Precision Mechanics and Optics in Budapest, (Hungary)* by whom all the subsequent ones and more recent models are manufactured. With these first instruments, Eotvos made his trial measurements outside the laboratory, at the foot of the Mount Gellert in Budapest in 1889. On the basis of the acquired experiences he constructed more suitable instruments, in 1890, which were used in the measurements made on Mount Sag in West Hungary, and were shown at the Hungarian Millennium Exhibition in Budapest in 1896. Using these instruments a great deal of valuable experimental data were collected, and in 1896 Eotvos gave a lecture in the Hungarian Academy of Science, which was published in Hungarian and in German.

The early instruments that were suitable for outdoor experiments were used in the vicinity of Budapest, but the first detailed measurements were made in 1901 on the ice of Lake Balaton. Since that time the surveys have been extended under the supervision of Dr. D. Pekar, member of the Hungarian Academy of Science, who by the way has been associated with and participated in Eotvos's work since 1893. After the death of Eotvos in 1919 the *Baron Roland Eotvos Geophysical Institute*

was founded under the direction of Dr. D. Pekar having for its main object the advancement of the scientific researches of Eotvos and the continuing of his geophysical field measurements.

Up to 1924 there was surveyed in several districts in Hungary an area totaling some 7.428 square km. in which were detailed the precise determinations of gravitational forces. Investigations were made along lines totaling some 1.063 km. to gain other gravitational data. Moreover these investigations were carried into India and some other foreign countries, and constant improvements were made in the instruments as the work advanced.

The essential of the Torsion Balance is a very fine wire suspending a light horizontal beam on the ends of which are small weights.

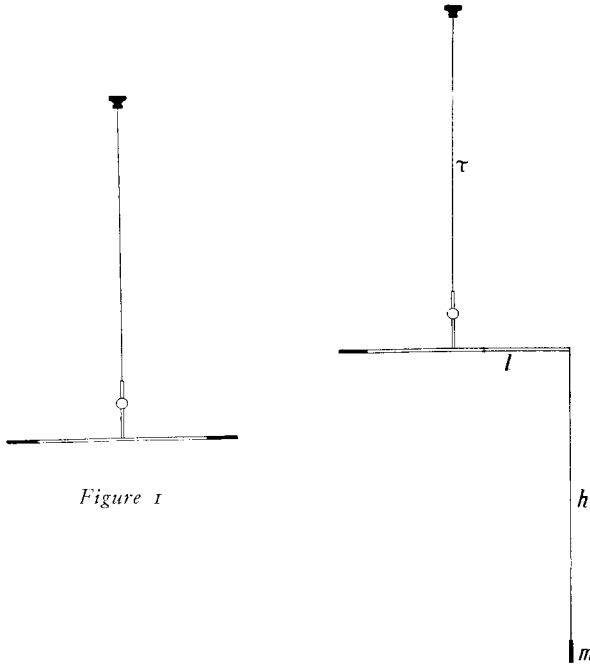


Figure 1

Figure 2

Two types were used by Eotvos in his gravitational researches. In type 1, (Figure 1) a torsion wire supports a horizontal beam on the ends of which are small weights. His later model is shown in type 2, (Figure 2). In place of the weights being in the same

horizontal plane as in Figure 1, one is suspended from the end of the beam by a small wire. The forces of gravity acting upon the two weights are in general not the same in magnitude and direction, and as a result the existing differences create a minute horizontal component by means of which the beam is turned in the horizontal plane against the elastic force of the torsion wire. Using the Torsion Balance of type 2 data for determination of the gradient may be obtained. Using the balance of type 1, only curvature data may be obtained, i. e. the measure of the variation of gravity in the horizontal plane. The Torsion Balance of type 2 consequently yields *four gravitational values*, of which the data for the gradients are especially important when drawing conclusions as to the subterranean configurations. For that reason this instrument is always used in the field measurements of the gravitational surveys.

In 1898 and 1899 newer models of these instruments were constructed and exhibited at the International Exhibition of 1900.

The cross section and the photograph of this early instrument called the single armed variometer of gravity, is represented in Figures 3 and 4 respectively. The forces of gravity acting upon the suspended beam bring it to rest in a position which is read by telescopic observations, a method which is commonly used in physics. Opposite the mirror on the end of the arm is the telescope and above the same is a scale. This arrangement enables the observation of even extremely slight angular changes.

On account of the great sensitiveness of the instrument, the oscillating balance is enclosed in a triple metallic case, which protects it against external disturbing effects such as currents of air, sudden changes of temperature, magnetic and electric influences, different radiations, etc.

The gravitational field of the earth is determined with detail and precision when measured with this instrument, such as is not at all obtainable using common "invariable pendulum." On the basis of the observed results important conclusions may be drawn as to the subterranean materials and its configurations, often detecting in this way valuable mining products. For that reason the Torsion Balance has gained many and varied practical applications.

It is worthy to note, for example, that the subterranean elevation of the strata of higher density (shown in Figure 5

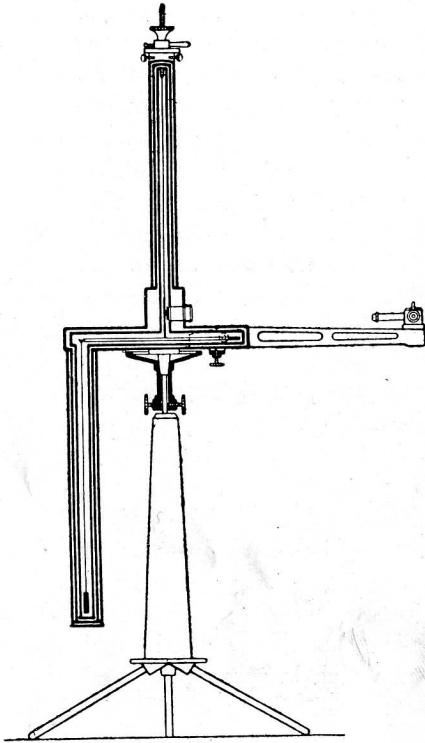


Figure 3

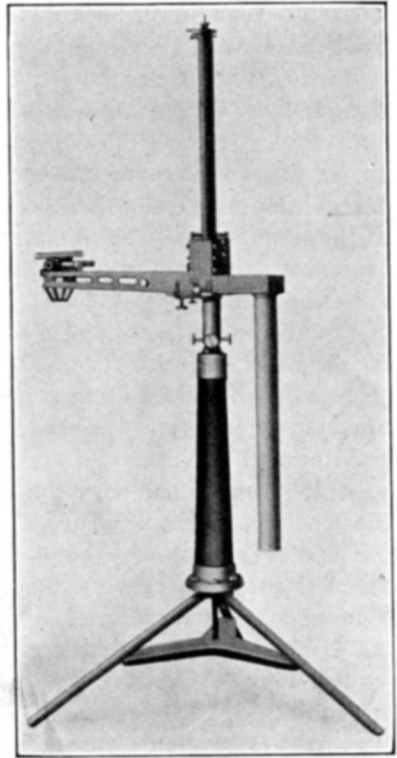
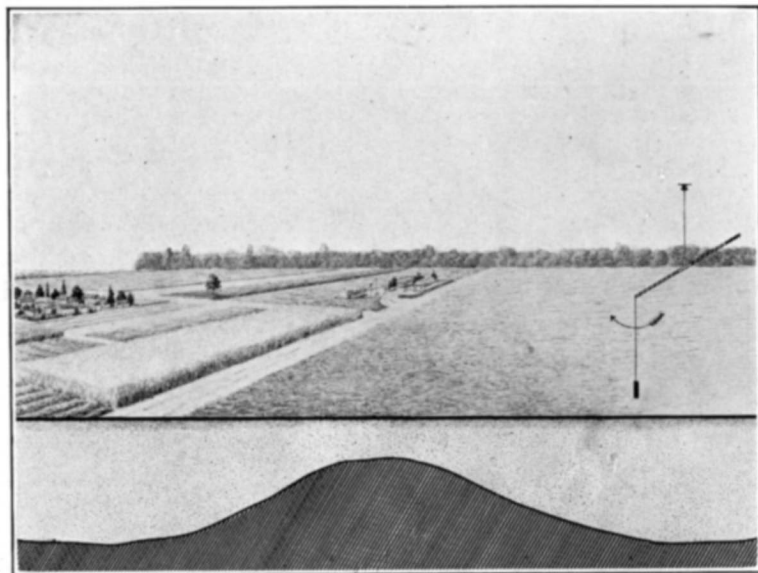


Figure 4

densely hactured) is nearer to the lower weight of the Torsion Balance than to the upper. The lower weight consequently has a slightly greater attraction than the other one, and accordingly the Balance is revolved in the horizontal plane according to the direction of the arrow. On account of the small value of the constant of gravitation— $66.3 \cdot 10^{-9}$  CGS—characterizing the attractive force, all these effects are very minute. For that reason the measurements by the Torsion Balance require a precision of about  $1 \cdot 10^{-9}$  CGS, i. e., to the one billionth part of a gram weight. To have a correct and clear idea of this extremely slight force let us consider the following comparison. Suppose by some mysterious machinery the small mass of a gram could be drawn out into a wire so long as to circle the earth 25 times, the weight of one millimeter of this wire could not be perceived by any

magnifying glass or microscope and would amount to one billionth part of a gram representing the sensitiveness of this instrument. With proper precautions the Torsion Balances having such extreme sensitiveness afford reliable data.



*Figure 5*

The Torsion Balance renders data for the computation of four unknowns required for the determination of gravity, a fifth unknown is the position the beam would assume under influence of no external force. To determine these five unknowns of gravity five equations are required, accordingly, observations are made by bringing the instrument in five azimuths, i. e., in five positions. This renders the survey work a little tedious and in order to eliminate these features Eotvos constructed in 1902 a double armed gravitational Torsion Balance, the photograph of which is given in Figure 6. This apparatus is the combination of two instruments mounted on a common pedestal set in opposite directions and forming an angle of  $180^\circ$ . With this instrument observations are made in three different azimuths, i. e., in three positions and give sufficient data to compute all the above mentioned four gravitational quantities. These quantities with the

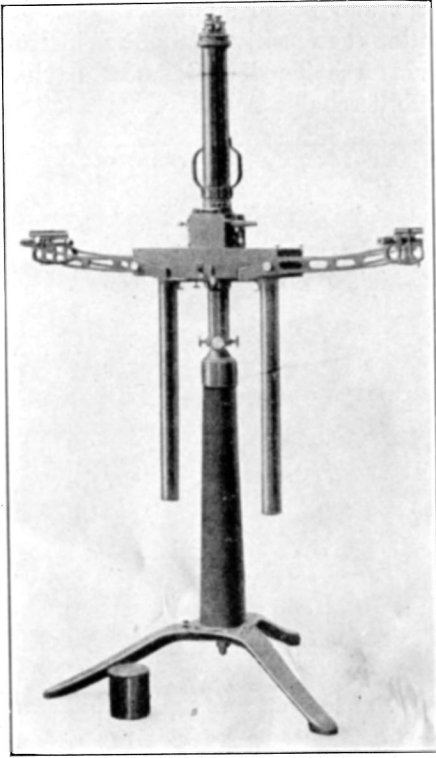


Figure 6

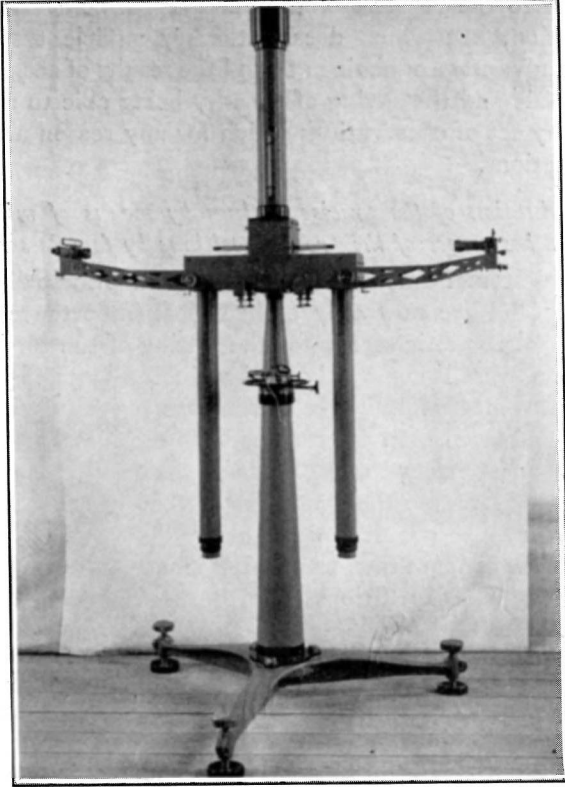
positions of rest of the two beams make six unknowns which are determined by three double observations. The arm of the torsion beam being 20 centimeter in length necessitated separating the instrument into several parts for transportation purposes. This was a big disadvantage in field operation, and in 1907 Eotvos constructed a new apparatus consisting of one part. Steady improvements were introduced in the construction of the oscillating balances and the instrument case from experiences gained by field measurements and of the systematic experiments made in the laboratory.

By perfecting the instrument and eliminating nearly all of the external disturbing effects the instruments give exact and reliable data under the most unfavorable meteorological circumstances. To facilitate transportation the new models are manufactured largely of aluminum; the weights of the oscillating balances are made of gold instead of platinum. The newly constructed models are considered the most practical field instruments satisfying all different pretensions of the measurements. The newest instrument is shown in Figure 7, and following advantages of its construction are of especial interest.

1. *Visual observation by means of telescope and scale.*

Eotvos made use of the photographic registering device and in 1900 exhibited in Paris several photographically registered





*Figure 7*

observations. Because of the proven disadvantages in field observation the registration method was discontinued. Some of the disadvantages encountered using this method are the heating effects of the lamp for the registering device; keeping the mechanism of this attachment in order, likewise the mechanism of the revolving device for the instrument; the developing of the photographic plates which becomes a task especially in out of the way places, and the taking of measurements from the plates. In certain territories it is a very great disadvantage to have to repeat some stations, and should trouble arise from any of the above causes there would be no alternative but to repeat the station, and in all cases a single repetition would not suffice. The apparent advantage of the automatic registering device is

in regards to the comfort of the observer, which is worthy of consideration, but which does not carry sufficient weight to offset the advantage of having at hand the results of each observation as made and the saving of time by being able to repeat instantly any set of observations which for any reason are not up to expectations.

2. *Elimination of the precise settings by means of micrometric screws and insurance of the proper positions by female screws.*

In the first instruments which were used principally in the laboratory and are now only of historical importance, Eotvos employed micrometric screws for the setting of the torsion head and telescopes, as is commonly used on instruments of precision. It soon proved that this mechanism was quite unsuitable for the field measurements. In transporting the instruments these precise settings changed and called for the readjustment of the same. For that reason these were eliminated in the field instruments and proper positions were assured by means of female screws. The experience then was that the instruments upon return from transmarine expeditions could be used without any readjustment.

3. *The arrangement for observation is very simple.*

The application of two telescopes and scales is incomparably simpler than the automatic mechanism for registering and revolving, even though the latter be constructed with skill and exactness.

4. *The arrangement for observation is reliable.*

The delicate automatic mechanism of other makes is not quite reliable even in case of the best construction. In observing with telescopes there is no question. Reading twice checks the possibility of error.

5. *In construction the mechanism is not at all delicate.*

In comparison the automatic mechanism is certainly delicate especially under bad meteorological conditions and needs careful treatment. The original Eotvos instrument is not only tropics-proof but also jolting-proof, when set for carrying.

6. *Great stability of the instrument.*

For the purpose of stability the instrument is mounted on a

light but massive pedestal. The stability of the turning axis is secured by a cone of 25 centimeter length. The pedestal is fastened by screws on a tripod having the setting screws on a circle of 54 centimeter radius. In this way the Eotvos instrument is of greater stability than the copies.

7. *The instrument itself is made in one piece.*

In transporting, the instrument is not separated into its parts, the lower tubes are not unscrewed etc. Accordingly, the instrument is not opened in the field and thus moisture and dirt is kept out, which sometimes caused trouble in the old models which were taken to pieces.

8. *Fastening the oscillating balance.*

The torsion beams and the hanging cylindrical weights are made fast from the outside so the instrument can be transported in any position.

9. *The handling of the instrument is very simple.*

The instruments with automatic mechanism are complicated. The Eotvos instrument consists only of three parts, i.e., the tripod, the pedestal and the instrument itself. The pedestal is fastened to the tripod with screws. The instrument is then set on the pedestal and adjusted making the turning axis vertical, the oscillating balances are released and the instrument is ready for observation.

10. *The ease of transporting the instrument.*

For field purposes generally, suitable boxes are provided. It is more suitable to employ special vehicles in which the three parts of the apparatus can immediately be placed as is shown in Figure 8. The transportation moreover, is facilitated by the slight weight of the instrument, which is manufactured largely of aluminum, with the exception of the parts used in motion.

11. *Absolute symmetry and uniformity in the distribution of masses.*

Constructing the instrument this principle is maintained in all parts of it, making the variation of temperatures of the different parts of the apparatus as uniform as possible when the external temperature changes.

12. *Insensitiveness against external disturbing effects.*

The oscillating balances and the interior parts of the instru-

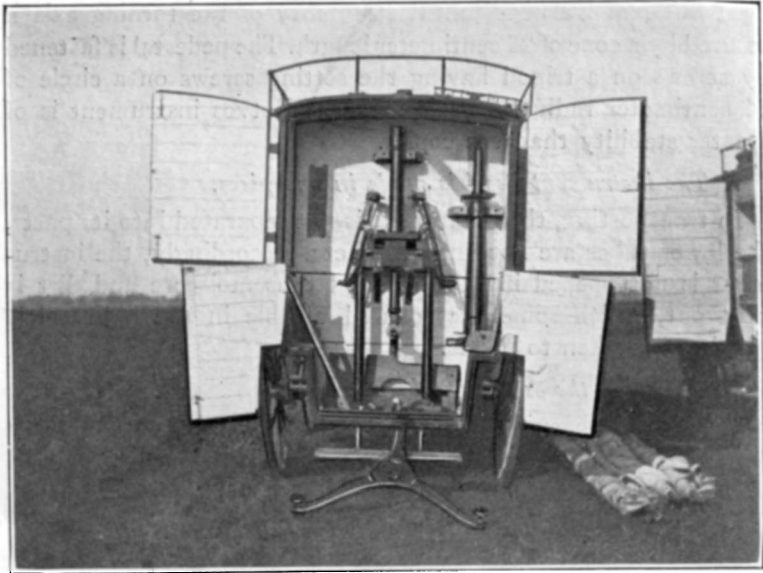


Figure 8

ment are so constructed in detail as to render the apparatus insensitive against external disturbing effects. The precise adjustment is made by special methods established in the laboratory.

13. *The most favorable form of the torsion beam.*

The old cylindrical form of the beam was changed. The same is now made flat and a flat gold weight fixed on the end of it. The shape of which is the most favorable theoretically and experimentally.

14. *Excellence of the torsion wires.*

Experiments have been in progress for many years with different preparations of wires of various materials. The wires are prepared by special methods to render them perfect as regards the torsion constant and the temperature coefficient. The best of these prepared wires only are selected for use for the balances.

15. *Extreme sensitiveness of the instrument.*

In employing good torsion wires and properly composing the oscillating balances a degree of sensitiveness is obtained which is greater than is required in field measurements. In accordance with the theory as developed, the irregularities of the earth's

surface in the immediate vicinity of the observation station, i.e., the terrain effects, must be computed separately and deducted from the data given by the instrument. This adds to the exactness with which the work is characterized and is significant of its completeness.

*The absolute sensitiveness of the Eotvos instruments is higher than that of any other Torsion Balances on the market.* The characterizing value of the absolute sensitiveness is  $\frac{m \cdot h \cdot l}{T} = 77 \cdot 10^3$  CGS, by which the absolute revolution of the torsion beam is indicated, being the gravitational gradient of one unit.

As published in the treatise of Dr. C. Heiland—*Die Brauchbarkeit der Drehwagen im Felde*, Zeitschrift für Instrumentenkunde 54. S. 98-95; 1925—the absolute sensitiveness of the Bamberg-Schweydar's instrument made by the Askaniawerke Berlin-Friedenau amounts only to  $69 \cdot 10^3$  CGS. In the same article the somewhat unfavorable value of  $56 \cdot 10^3$  CGS is published for the Eotvos-Suss instrument, but this information relates to the first double Torsion Balance made in 1902 and shows the excellence of the 24 years old model. The above new value— $77 \cdot 10^3$  CGS—relates to the instrument No. 14257 delivered to the "Exploration" Bodenuntersuchung und Verwertungs Gesellschaft, Berlin in 1924. There was also brought out in the same treatise, that for the instruments of Hecker, made by the Gesellschaft für praktische Geophysik, Freiburg I. Br. this value is only of  $40 \cdot 10^3$  CGS.

#### 16. *Application of strongly magnifying telescopes.*

On the Eotvos instruments 25 fold magnifying telescopes are mounted, so that the scale divisions of half a millimeter appear so large in the telescope that the tenth part is easily observed. Accordingly the gradient, corresponding to the revolution of 1/10 scale division, i. e., the effective sensitiveness of the instrument amounts to  $0.5 \cdot 10^{-9}$  CGS. *The Eotvos model is accordingly about twice as sensitive as the best other instrument on the market.*

As published in the above mentioned article, the effective sensitiveness of the Schweydar-Bamberg instrument amounts to  $0.9 \cdot 10^{-9}$  CGS and of the other instruments is still larger showing the less sensitiveness of them. There is also given the unfavorable value of  $1.5 \cdot 10^{-9}$  CGS for the Eotvos instrument, but

this relates to the apparatus manufactured in 1902 and is quite in error, because in computing the same, the effect of the strongly magnifying telescopes was not taken in consideration.

By observing visually, it is obvious that having the scale at a distance of 1 meter and employing such telescopes, whereby the  $1/10$  scale division of 1 millimeter is read off precisely, the same exactness can be obtained as having the scale of  $1/2$  millimeter at a distance of  $1/2$  meter and employing stronger telescopes, so the  $1/10$  of the scale division can be observed precisely. In both cases equal angles correspond to the  $1/10$  scale division with equal observed exactness, and the effective sensitiveness of both instruments are the same, whereas according to Heiland's computation, it would be different in the relation of 2:1. At any rate it seems unfair not to take in consideration the exactness of the observing arrangement in calculating the effective sensitiveness.

17. *Reliability of data of the instrument.*

Because of the above detailed constructional advantages and other arrangements not as yet mentioned the Eotvos instruments are reliable whether used in day or night time and under the worst meteorological conditions. To protect the Balance against the inclemencies of the weather and to be able to work under unfavorable conditions the instrument is placed in a double walled hut of waterproof canvas filled with heat insulating material. When observing in tropics and in daytimes a sun tent or fly spread above the hut is recommended.

18. *The strong damping of the oscillating balance.*

To hasten the observation period the instrument is adjusted but once for each station, then a certain period of time allowed for the oscillating parts to come to rest. In observance of the principles of the instrument this period should be kept uniform. Although it would be possible to increase the damping by employing a suitable electromagnetic mechanism, this construction would jeopardize the reliability of the instrument's data.

19. *The speedy execution of the observation.*

It is possible to work with the Eotvos instrument with more speed than with other ones. After completion of the observations the numerical values wanted for computation are available immediately, whereas in case of registration instruments the data

is available after developing and measuring of the photographic plates. It should be emphasized that dependable results cannot be obtained by taking one set of observations only, no matter the make of the instrument used, and such a procedure may make mistakes possible and render the results quite doubtful.

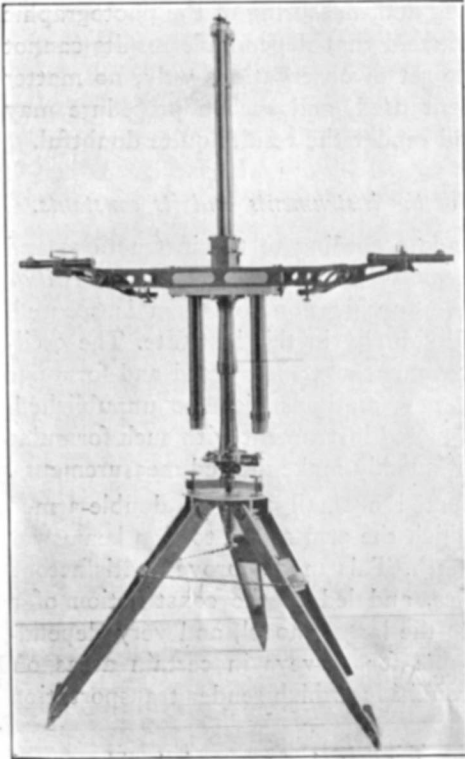
20. *The manufacturing of the instruments and its constants.*

The instruments are made according to the instructions and under the control of the *Baron Roland Eotvos Geophysical Institute* and thus an irreproachable specification for them is secured. All apparatus is tested individually in this institute. The oscillating balance and the instrument are constructed and formulae determined by employing new methods hitherto unpublished. This method insures a completed instrument with such formulae as are essential to fully and quickly make desired measurements.

In 1908 Eotvos constructed a small type of double-armed instrument, Figure 9, in which the arm of the torsion beam was only 10 centimeters in length. This model proved satisfactory in India and in the tropics, and led to the construction of a small instrument similar to the larger model, and very dependable. It is especially suitable for surveys in certain areas on account of the territorial conditions which render transportation difficult.

In 1909 Eotvos likewise constructed a type of double-armed Torsion Balance, the arm of the torsion beam being only of 5 centimeters length. This instrument proved impracticable because it failed properly to eliminate the influence of external disturbing effects. By diminishing the dimensions of the instrument beyond a certain limit, the disturbing influence of external effects increases, rendering the data unreliable. For that reason utmost care must be taken in constructing small models, and the use of too small an instrument is generally not recommended.

Many scientists and experts from all parts of the world have visited the Eotvos Institute and studied the Torsion Balance in the laboratory as well as in the field. As a result this new gravitational method has become quite popular and is widening into various spheres. **The different models constructed in foreign countries are based directly or in-**



*Figure 9*

**directly upon the original Eotvos instruments.** Mention is made only of the following details on the subject.

Eotvos placed all the data of his instruments made up to 1902 at the disposal of O. Hecker, who at that time was associated with the Royal Prussian Geodetic Institute in Potsdam. M. Fechner, mechanic of the institute, made the first German instrument under instruction of Eotvos. On the basis of the Potsdam instrument Schweydar constructed his model at the Askaniawerke in Berlin-Friedenau. J. Koenigsberger,

Professor at the Freiburg University, has spent many months of study in the Eotvos Institute of the field measurements carried out in Hungary. Moreover, Eotvos loaned him a small type instrument which he had made in 1908, and with which he made measurements in Germany in company with O. Hecker. On the basis of this instrument has been constructed that model which is now being put on the market by the Gesellschaft für Praktische Geophysik in Freiburg i.Br. In London L. Oertling started construction of a new instrument modeled from the original Eotvos and from the types manufactured by other firms. The essential parts of all these different instruments are mostly made in accordance with the first Eotvos double-armed Torsion Balance, with the main point of fabrication consisting in the skillful construction of the automatic registration.



The Torsion Balance of Eotvos is a reliable instrument of extreme sensitiveness and therefore may be used for various researches in science as well as in practical life. In Physics small forces may be measured by it. For example Baron R. Eotvos, Dr. D. Pekar and E. Fekete performed their precise experiments with the Torsion Balance proving the proportionality of inertia and gravity with an exactness of  $1/200,000,000$ , by which work they won first prize in the international competition of the Göttingen University. The experimental verification of this principle is also important because it is one of the cardinal axioms of the Einstein theory of general relativity. In *geophysics* useful directions can be obtained for the solution of different problems, mention being made of but one, and that, the principle of isostasy. In seismology this instrument gives the means of detecting the dangerous tectonic lines and seismologic or vulcanic dislocations of masses. In *geodesy*, the real form of what might be termed a regular surface of the earth may be determined by the Torsion Balance. In *geology* using the data of this instrument, important conclusions can be drawn as to the subterranean strata and their configuration.

Among the practical applications prospecting with this instrument is of greatest importance. With the aid of the measurements it is possible to determine the course of the subterranean strata to detect subterranean slopes, to establish the highest and the lowest places of the strata, i. e., the anticlines and synclines which data are in most cases very important with regard to mining. To determine with certain exactness the subterranean steps, the faults where the mining stops, etc. Valuable materials and mining products may also be found by this method, directly or indirectly.

I. *Materials found directly* are those which cause gravitational disturbances on account of their density, i. e., their specific gravities differ from that of the surroundings. From the various applications mention is made of two groups. On one hand detecting materials of greater density than the surroundings, as for example different deposits of ore, etc.; on the other hand materials of less density, for example salt bodies, and sometimes coal, as has been proved in the Torsion Balance Surveys carried out in Hungary. In all these cases the boundaries of such are determined easily and exactly.

II. *Materials found indirectly* are those which do not cause

gravitational disturbances but are detected in connection with some subterranean configurations discoverable by means of the Torsion Balance. In this case there are many possibilities of application of which the most important is *the search for oil and natural gas*. In accordance with geological information these are found under different conditions as follows:

1. Petroleum and natural gas are found on the slopes of salt masses as has been proven especially in Germany and America. The boundaries of such salt bodies because of its less density can be determined exactly as above explained.

2. They also are to be found on the boundaries of igneous rocks or magmatic intrusions. (According to American experiences). The boundaries of these masses of greater density can also be precisely determined.

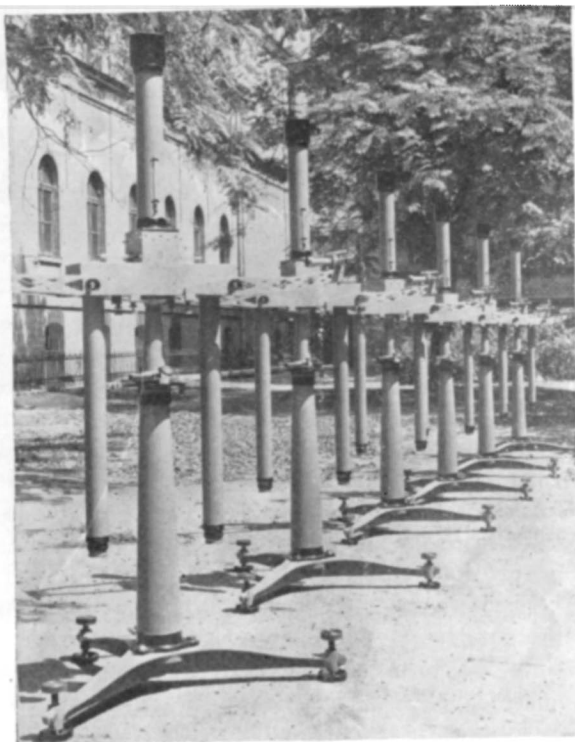


Figure 10  
*Series of Torsion Balances shipped to America.*

3. Oil and gas are found on the subterranean elevations, on the anticlines of the domes as has been proven by the measurements made in Hungary. These configurations can also be detected by the Torsion Balance. In a word, in all these cases it is possible to find the oil and natural gas by this direct application of the gravitational method.

As has been repeatedly mentioned, the Torsion Balance gives directions as to the subterranean configurations. In this way for example it is possible to determine the trend of the water containing strata and the data of its depth as was proven by Budapest measurements. The Torsion Balance may also be employed in other cases in which the subterranean configuration is connected with some practical advantages, etc. It is especially important to use this instrument for surveys in certain territories where the geologist can obtain data only on the basis of very expensive borings. In hilly or mountainous land on points of the outcrops the dip of the strata can be measured, and thus these areas are sufficiently open for geological researches. Owing to the unfavorable circumstances of flat regions it is extremely important to procure the necessary information by some other method, and for this purpose the original Eotvos Torsion Balance is a helpful and very suitable instrument.