69. *Invariable Pendulum of Tungsten for Relative Measurements of Gravity.*

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Invariable pendulum for gravity survey is usually made of brass, with agate knife-edge. The metal can be easily cast and shaped that there is little trouble in the construction. But owing to the high expansion coefficient, small tensile strength and hardness, and its liability to be attacked by acids, the invariability of brass pendulum cannot be always insured. As regards the expansion by heat, invar pendulum can be used with advantage where there is large fluctuation of temperature, but as the substance is ferromagnetic, the period of the pendulum is affected by the earth's magnetic field, and by the electric current passing near the place of observation. This factor is rather uncontrollable, and makes the use of the invar pendulum somewhat doubtful in accurate measurements. In addition to this, both brass and invar pendulums are provided with agate knife-edges, which are inserted into the body of the suspension rod. By the variation of temperature, the mutual attachment of agate and the metal is liable to change, which is another source of error in the measurements. To avoid this error, the construction of *monometallic* pendulum was considered desirable.

After various examinations of the metal suitable for constructing a gravity pendulum, I came to the conclusion that tungsten is after all the best material for the purpose. The density of tungsten is 2.3 times that of brass and 2.4 of invar, so that the pendulum can be made in a compact form without losing the necessary weight; the tensile strength being 9 times that of brass, slender rod can be used for supporting the bob; the thermal expansion being only 0.26 that of brass, there is little risk of incurring an error due to temperature variation, which is the most important factor in the measurement. Moreover tungsten is very hard that it cannot be scratched with a knife nor with steel tools; a knife-edge can be made of it, and the dream of a monometallic pendulum can thus be realised. Unlike brass and invar, the metal is

insoluble in hydrochloric, sulphuric and nitric acids, and the risk of deteriorating the surface is much lessened.

A great difficulty was encountered in obtaining a large mass of tungsten for constructing a pendulum, on account of its high melting point (3400°C.) The bob was made cylindrical and of one mass with the suspension rod, to which a knife-edge of the same metal was attached by boring a hole through it to let the rod pass tightly ; after adjusting the period, the rod and the knife-edge were fixed by passing two pins of tungsten wire through them. On account of the hardness of the material, the boring of the metal was not an easy task. Diamond sands were used for the purpose with no good result, but Messrs. Ayabe and Sato, mechanics in the Institute, finally succeeded in overcoming the difficulty. Four half-second pendulums were constructed, the only part not made of tungsten being a light glass mirror of about 8 mm. diameter attached to the upper face of each knife-edge for the determination of the period by coincidence method. The upper face can be polished to serve as a reflecting plane.

In the usual brass pendulum, agate knife-edge rests on an agate plane, the same material being brought into contact : in the present arrangement, the tungsten knife-edge was made to rest on a plane face of stellite No. 23 which is little harder than tungsten. The four pendulums can be suspended in a cylinder of 15 cm. diameter on account of their compact form ; the cylinder can be easily evacuated, and the vacuum kept intact for a long time with mercury seal, as tungsten cannot be amalgamated and the cylinder is made of massive iron. For observation, the upper face of the cylinder was covered with a plane glass plate, and a lid of iron plate above it with a hole for observing the motion of the pendulum. The temperature of each pendulum can be measured by means of thermo-junctions of copper-constantan placed near it. In order to keep the temperature of the pendulums constant, the vibration case was made small, and fixed to strong iron stand, which can be bolted to three wooden pillars deeply buried in the earth. By digging a hole in the ground the case can be placed snugly in it, and its temperature kept nearly the same as that of the surrounding soil. By this arrangement, the fluctuation of temperature can be greatly avoided, and the observations conducted in tents. Owing to the compactness of the pendulums and the vibration case, there is great facility in the transport of the apparatus.

The whole apparatus was taken to the Geophysical Institute of the University of Kyoto and tested. The correction for the yielding of the

support was found to be exceedingly small, amounting to two units in the seventh decimal of a second. For these observations I owe to Prof. R. Otani and his associates. It is intended to take the apparatus to Corea and Manchuria, where we are compelled to make tent observations.

The annexed diagrams show the pendulum and the vibrating apparatus.

Vibration Apparatus.

No. 1.
1/10 Natural Size.

Elevation.

No. 2.
1/10 Natural Size. Plan.

Starter.

No. 3.
1/4 Natural Size.

Tungsten Pendulum.

No. 4.
1/4 Natural Size.