B5

Theory:

$$F = \frac{GmM}{r^2}$$ (Force between M and m)

$$\tau = \vec{l} \times \vec{F}$$

$$= \frac{l\,GmM}{r^2}$$ (Torque due to both mass pairs)

$$\tau = -K\phi$$ Twisted wire resists torque. Hooke's law

$\phi \equiv$ angle of twist of wire

$$T = 2\pi\sqrt{\frac{I}{K}}$$ Period of tortional pendulum

$$I = \frac{ml^2}{2}$$ Moment of Inertia, small masses on rod

$$\theta = 2\phi$$ Reflecting laser from plane mirror.

$$-K\phi = \frac{l\,GmM}{r^2}$$ Equal Torques

$$\phi' = 2\phi$$ Reversed direction of masses. Total deflection

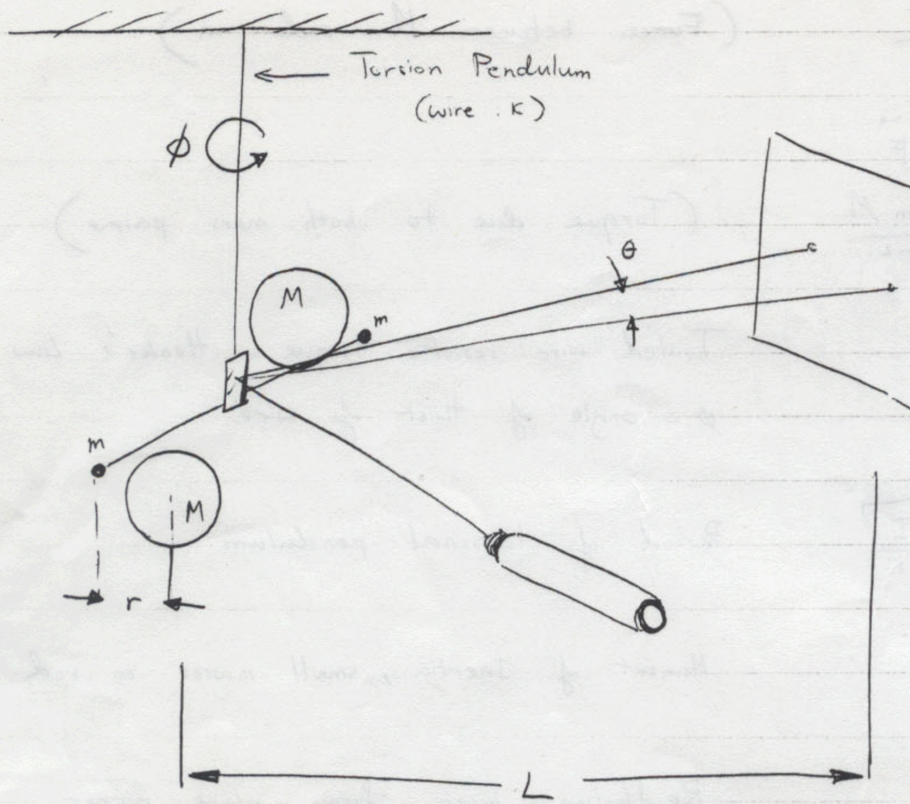
$$\theta = \frac{4\,l\,GmM}{kr^2}$$

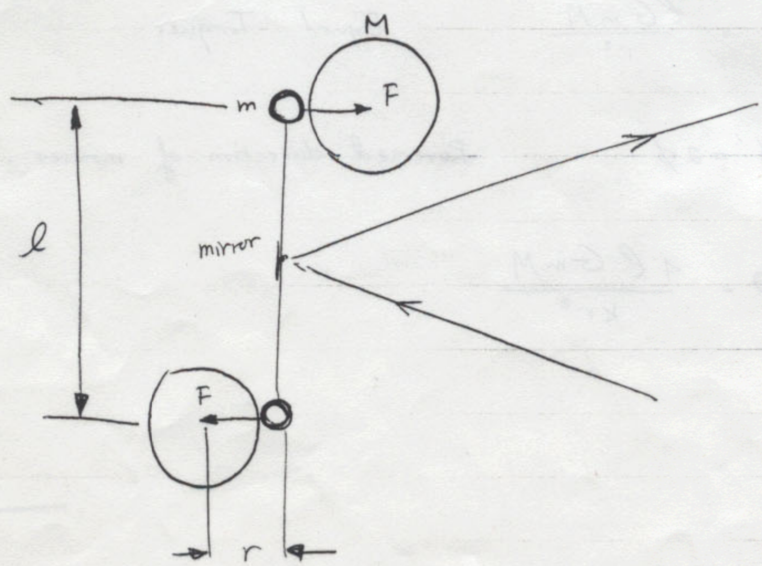
→

Cavendish Exp.

B5

Theory:





3.3.2 Zero adjustment

- The gravitation torsion balance must be aligned vertically (see 3.3.1).
- After assembly, the apparatus should have been left for at least one day in adjusted and unlocked state before final zero adjustment, as in the beginning the torsion band always still elongates a little. This will save time.
- At first, remove the large lead balls ③.

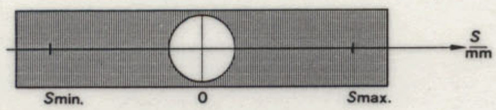


Fig. 9

Lock the system by means of knurled head screws ⑤ and bring it to oscillation by unlocking.

Watch the light-spot over a longer period (approx. 8 mins.) (Fig. 9). The max. deflections S_{min} and S_{max} of the light spot are limited by the small balls touching the casing walls. The effective measuring range lies within these limits.

Mark the two extreme values of the slowly moving light spot left and right on the projection wall (scale). Observe which rest position the system tends to take.

If this rest position deviates greatly from the centre between the above mentioned extremeties, turn the torsion head ⑪ through a small angle towards the desired zero point after loosening the lateral knurled head screw ⑫. Then lock the torsion head again.

Watch the zero again and repeat the procedure until the desired zero position $S = 0$ is attained.

> **Important Note:**
>
> To reduce the time required to perform the zero checks, a small, strong permanent magnet will be very helpful (e. g. the floating magnet from 510 44):
>
> Lead is repelled by magnets due to its diamagnetic properties. Hence, if one of the small lead balls approaches the casing wall, hold the magnet close to it for a short time until the system reverses.
>
> If this is repeated several times, the gravitation torsion balance will quickly come to rest.

When zero adjustment is completed, place the large lead balls on the swivel support ④ left and right. Move the support (as in Fig. 2) carefully until the large balls touch the casing wall.

The light spot will then balance out to its final rest position which is approx. $0.015\,L$ (L = distance between scale wall and rotary mirror) left from the scale zero.

The unlocked gravitation torsion balance is ready for measurement.

When the ball has moved to the opposite position, the light spot balances out to an equal limit value right from the zero. In mid position of the large balls, the effective gravitational forces compensate each other; the light spot goes to zero position.

The firmly fitted measuring assembly need not be locked. This is only advisable if you cannot prevent unauthorized persons to touch the apparatus.

Technical Data

(Fig. 3)

Small lead balls

Mass: each m_1 = 0.015 kg
Ball radius r_1 = 6.9 mm

Distance of center of gravity from the axis of rotation:
d = 50 mm

Large lead balls

Mass: each m_2 = 1.5 kg
Ball radius: r_2 = 32 mm

Distance of center of gravity between large ball when touching the wall and small ball in mid position:
s_o = 46.5 mm (see Fig. 3)

Period of oscillation of the system: T = approx. 10 mins.
Logarithmic damping decrement: Δ = approx. 0.7.
Directional quantity of angle of the torsion band:

D = approx. $8.5 \times 10^{-9}\ \frac{\text{Nm}}{\text{rad}}$

Difference between the light-spot end indications with the large balls turned to the left or to the right:
S_1 = approx. 0.03 L
(L: Distance between scale wall and rotary mirror)

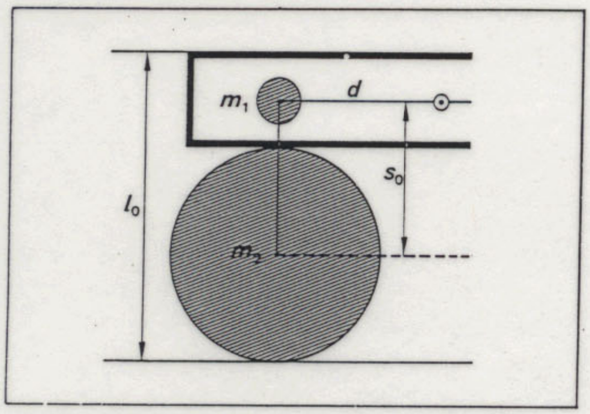


Fig. 3 To determine $s_o = \frac{L_o}{2}$, measure L_o with a caliper gauge!

3 Use

3.1 Additionally required equipment for p· a solid wall:

	Cat. No.
1 Stand base, length of sides 28 cm	300 01
1 Pair of levelling screws for 300 01	300 06
2 LEYBOLD multiclamps	301 01
or 1 LEYBOLD multiclamp (301 01) and 1 Rotatable clamp (301 03)	
1 Stand rod, bent at an angle, 60 cm long	300 52
1 Lamp housing	450 60
1 Lamp, 6 V, 30 W	450 51
1 Single-lens condenser with sliding aperture selector	460 17
1 Voltage source, 6 V, e. g. Transformer, 6 V, 30 W	562 76

For faster dying out of the oscillations:

1 Floating magnet	510 44
2 Scales, 1 m, with mm-graduation, self-adhesive (Spare Part No. 690 32)	
1 Piece of wire or thread, as thin as possible, approx. 15 cm long	
and/or Adhesive tape, 4 cm long	

Assembly aids:

1 Drilling machine
1 Stone drill
1 Dowel, 6 mm I. D.
1 Wood screw, 100 mm long, 6 mm dia.
1 Screw-driver
Gypsum

Additional measuring instruments:

1 Precision vernier callipers	311 54
1 Time measuring instrument, e. g. 1 Stop-clock	313 05
or	
1 Metronome	313 11
or	
1 Electric stop-clock	313 04
or	
1 Counter P	575 45
or	
1 Electronic stop-clock and relay	313 01
or	
1 Digital counter	575 50

3.2 Assembly

Aim: to achieve an experimental assembly which is always ready for use – according to Fig. 2.

3.2.1 Preconditions to be checked:

– There must be a solid wall enabling to suspend a large stand base by its apex borehole at approx. eye-level.
– Above the screw fixture there should be a free space for the carrier tube of at least 30 cm (no breaks, no ceiling).
– It should be possible to mount an at least 0.5 m long scale at a distance of at least 5 m from the site selected for the gravitation torsion balance, at a height of approx.

$\frac{L}{4}$ above the height of the rotary mirror.

(Inclination of light spot 15°; $L \tan 15° \approx \frac{L}{4}$)

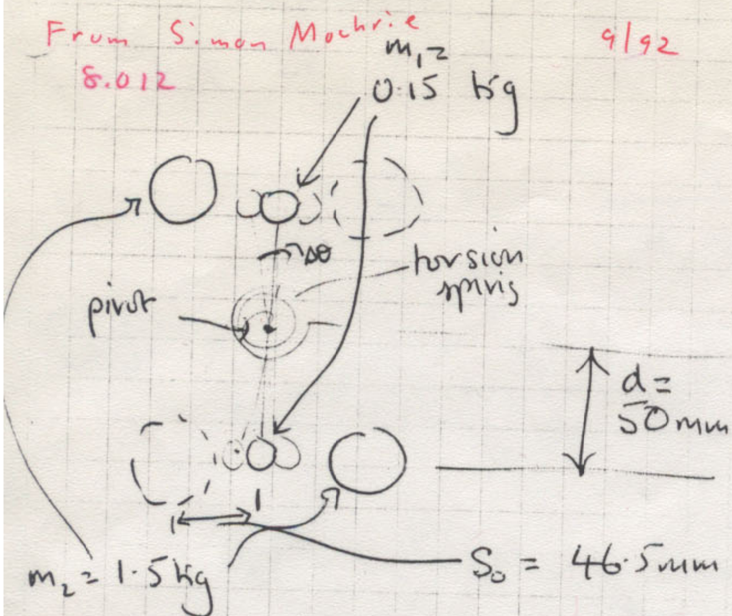
The angle of inclination of the light spot and hence the height of the scale may be reduced using a rotatable clamp (301 03) to fasten the lamp.

B5 THE CAVENDISH EXPERIMENT B5

Cavendish Experiment (42)

From Simon Mochrie 9/92
8.012

(1)



I ignore force between small mass & distant big ball
⇓
Some significant error. See HW.

torsion balance responds as follows

Torque = Force × perpendicular distance = $D(\frac{1}{2}\Delta\theta)$

with $D = 8.5 \times 10^{-9}$ m N rad^{-1}

gravitational force $F \simeq \frac{G m_1 m_2}{S_0^2} \times 2$

i.e. $2Fd = D(\Delta\theta)$

$$\left(\frac{4G\, m_1 m_2}{S_0^2}\right) d = D(\Delta\theta)$$

$$\frac{4}{8.5\times10^{-9}}\left(\frac{6.67\times10^{-11}\,(1.5)^2\times10^{-2}}{(4.65)^2\times10^{-4}}\right)5\times10^{-2} = (\Delta\theta)$$

10^{-9}

6.9×10^{-10} N

$$\frac{4\times6.9\times5}{8.5}\times10^{-3} = 16.23\times10^{-3} = 0.016 \text{ rads} = 0.9299^\circ = 0.93^\circ$$

B5 THE CAVENDISH EXPERIMENT B5

From Simon Mochrie

or
$$G = \frac{D(\Delta\theta)}{d} \Big/ \left(\frac{4 m_1 m_2}{S_0^2}\right) \quad (2)$$

$$= \frac{D S_0^2}{4 d m_1 m_2} \Delta\theta$$

$$= \frac{8.5\times10^{-9}\ (4.65)^2\times10^{-4}}{4 \times 5\times10^{-2}\ (1.5)^2\times10^{-2}} \Delta\theta$$

$$= \frac{8.5 \times (4.65)^2}{4.5} \times 10^{-10} \Delta\theta$$

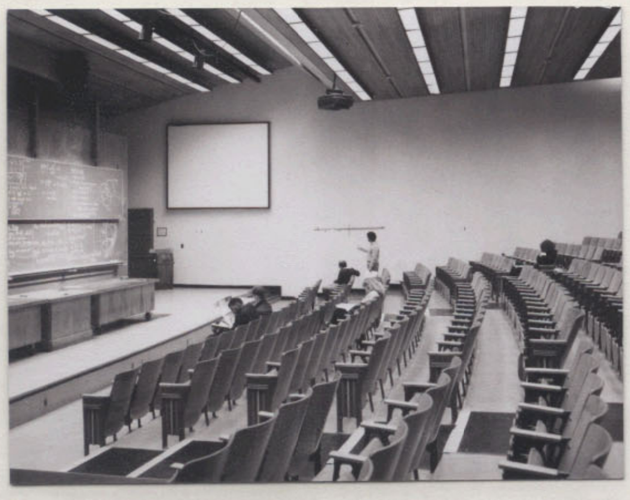
$$= 4.008425 \times 10^{-9} \Delta\theta$$

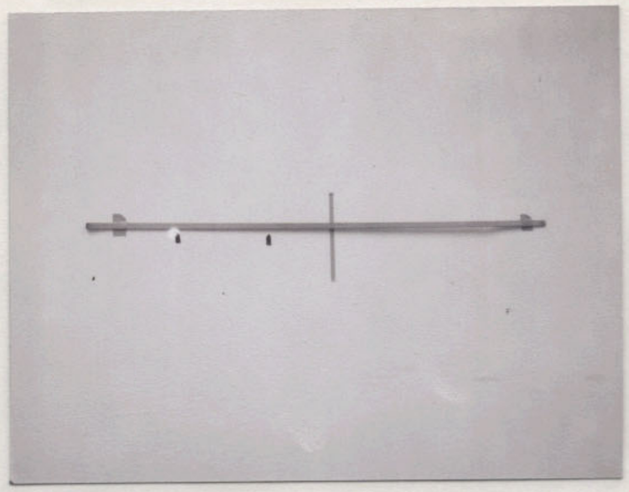
$(4.084 \times 10^{-9})\ 1.6\times10^{-2} = 6.534 \times 10^{-11}$

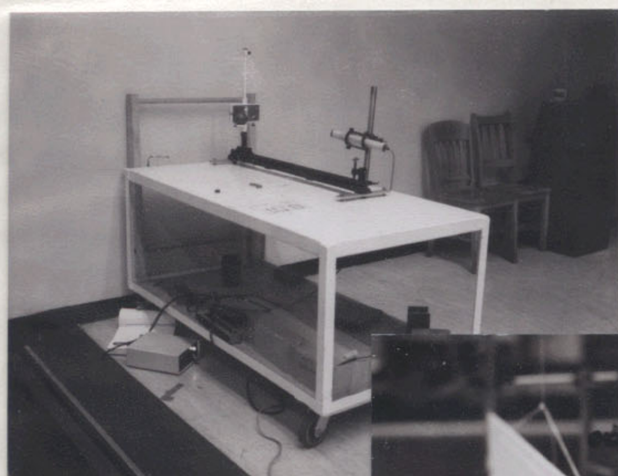
B5 THE CAVENDISH EXPERIMENT B5

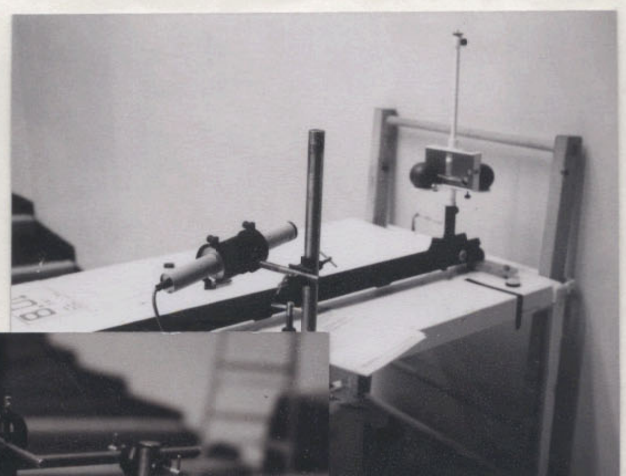
DYNAMICS - Gravitational Forces

A Cavendish apparatus is used for the experimental verification of Newton's law of universal gravitation. The period of oscillation is ≈ 10 minutes. There are specific problems using this demonstration in a 50 minute lecture.









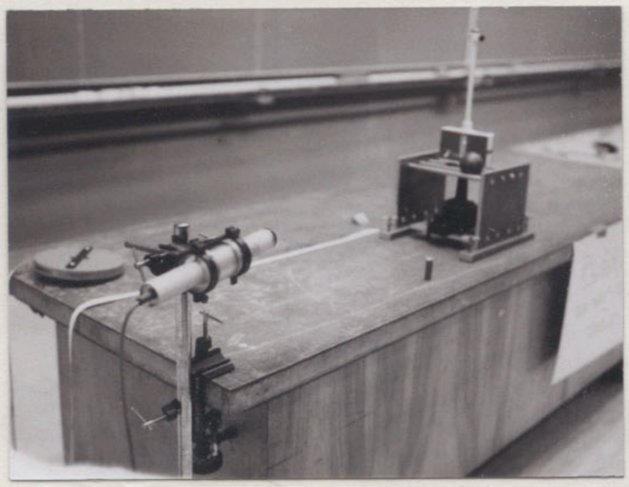
B5 THE CAVENDISH EXPERIMENT B5

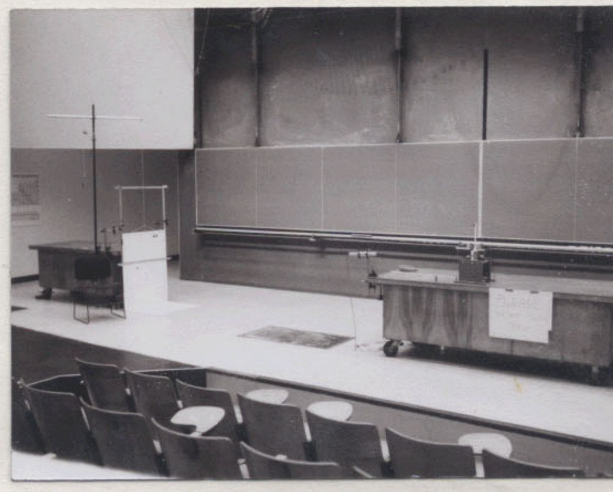
DYNAMICS - Gravitational Forces

This is another way of showing the Cavendish during lecture. The damping is plotted on a movable fomecore screen used as a scale. The scale is moved up 2cm per minute after the balls are moved.

The distance from the laser to the scale is 5M.

NOTE: Temperature seems to affect the demo.





11/81 – Brs –

Instruction Sheet

332 10

Gravitation Torsion Balance

This highly sensitive torsion balance with light-spot reading is used to demonstrate mass attraction and to determine the gravitation constant.

Measuring principle:

The oscillatory system with long period of oscillation T and known mass is disturbed in its static equilibrium by the action of gravitational forces of external masses and performs damped oscillations. The active force between the masses may be derived from the motion in time of the oscillation as well as from the new equilibrium position after dying out.

Examples of Experiments:

- Determining the gravitation constant according to the acceleration method
- Determining the gravitation constant according to the full-deflection method

Bibliography: Descriptions of Experiments for 332 10.

1 Safety Note

□ Suspend the gravitation torsion balance so that it is not accessible to unauthorized persons.

2 Standard Equipment, Description, Technical Data

① *Metal casing* with glass plate and inner acrylic glass screens to avoid air currents.
Dimensions: approx. 15 cm x 8 cm x 2.9 cm

② *Small lead ball* (2 contained in standard equipment)

③ *Large lead ball* (Spare Part No. 68 322, 2 included in standard equipment)

④ *Swivel support* for the large balls ③

⑤ *Knurled nuts* for locking the torsion balance

⑥ *Adjusting ring* for height adjustment of the swivel support ④

⑦ *Short rod* for securing to a permanent support, 12 mm dia.

⑧ *Concave mirror* for the light-spot indicator, focal length approx. 30 cm

⑨ *Torsion band,* made of bronce
Length: approx. 26 cm
Cross-section: 0.01 mm x 0.15 mm
Replacement:
1 m torsion wire on plastic reel (Spare Part No. 68 320)

⑩ *Carrier tube* for torsion band ⑨
Length: approx. 26 cm

⑪ *Torsion head* for zero adjustment

⑫ *Knurled head screws* to lock the torsion head ⑪

Furthermore, the standard equipment comprises:
2 scales, 1 m, with mm-graduation, self-adhesive (Spare Part No. 69 032)

Packing material:

2 metal clamps to protect the apparatus when transporting it (approx. 4 cm wide).

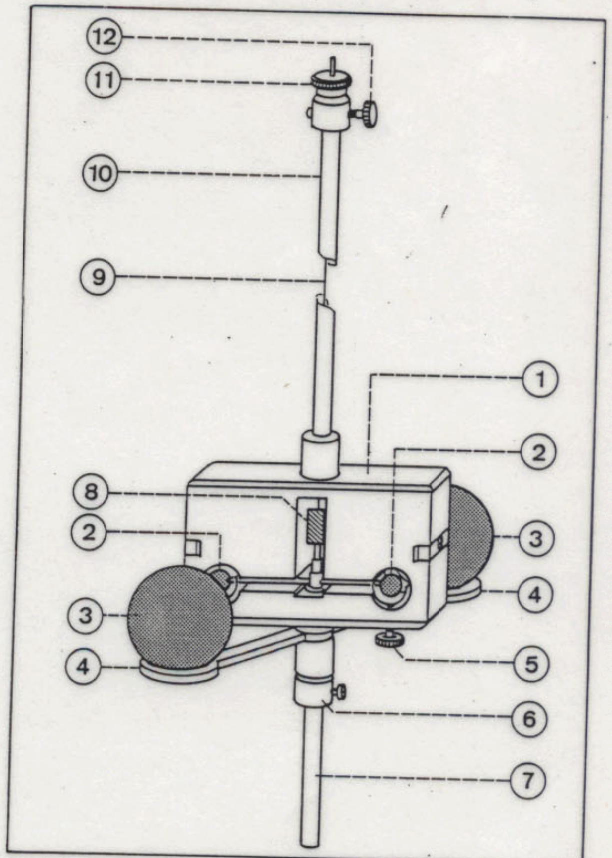


Fig. 1 Standard equipment of gravitation torsion balance (332 10)

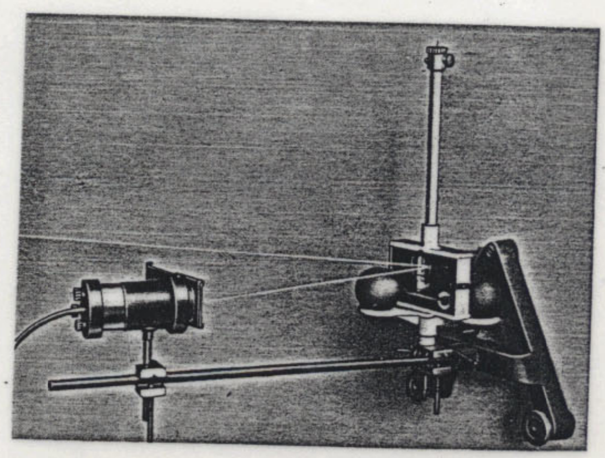


Fig. 2 Ready-to-operate set-up of gravitation torsion balance with additional equipment

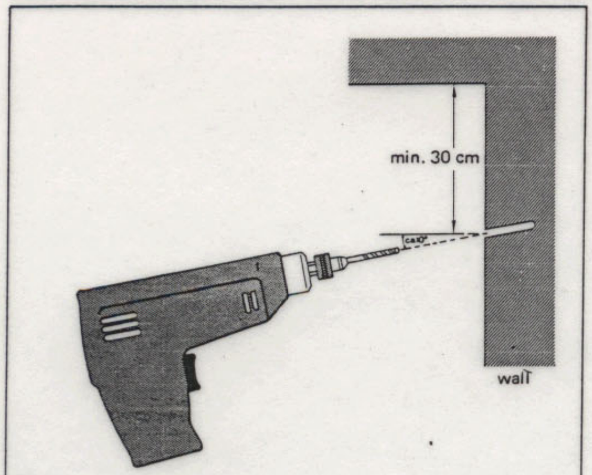


Fig. 4

- Make a hole in the wall using a stone drill (8 mm dia.) holding it at a slightly inclined angle. Observe minimum distance from any corbelings of the wall (Fig. 4).

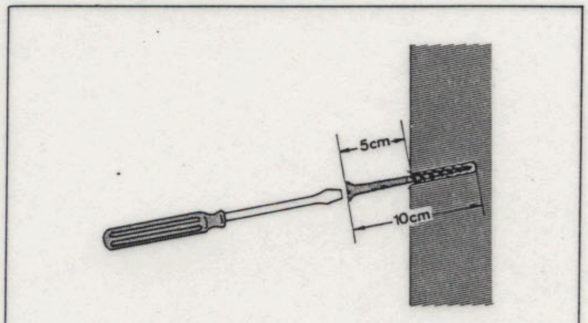


Fig. 5

- Apply a dowel (8 mm dia.) with gypsum and screw in a wood screw (10 cm long) leaving approx. 5 cm (Fig. 5).

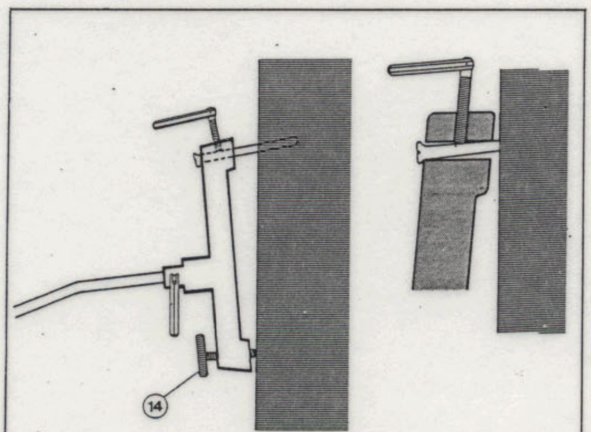


Fig. 6.1 Fig. 6.2

- Suspend a large stand base by its apex borehole and secure it (Figs. 6.1 and 6.2).
- Align the stand base so that it is parallel to the wall using the levelling screws ⑭, (Figs. 6.1 and 7).

  If the levelling screws should press themselves into the wall, put something solid underneath.

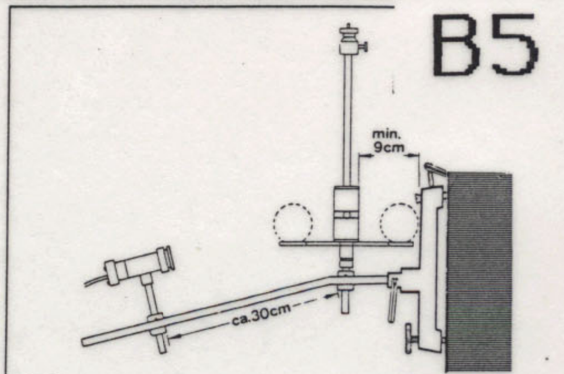


Fig. 7

- Further assembly according to Figs. 7 and 2.

3.2.2 Setting up the projection device for the light spot

Mount the condenser to the lamp. Stretch a thin thread over the centre of the large aperture transverse to the sliding diaphragm, or apply adhesive tape so that its edge, which is particularly suitable as a light mark, is positioned accordingly.

Produce a sharp image of the light mark on the scale on the opposite wall ba shifting the lamp.

Project a vertical image of the lamp filament on the concave mirror by means of the condensor, turning and sliding the lamp insert.

3.3 Adjustment instructions

3.3.1 Vertical adjustment of the gravitation torsion balance (Fig. 8)

- Unlock the suspension by loosening the knurled head screws ⑤.
- Readjust the levelling screws ⑭ of the stand base (see Fig. 6.1) by turning them until the torsion band is suspended precisely in the axis of boreholes ⑬.

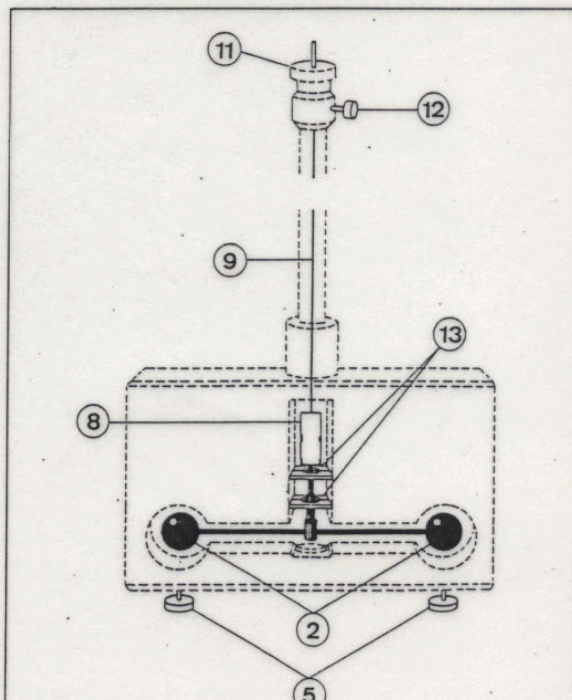
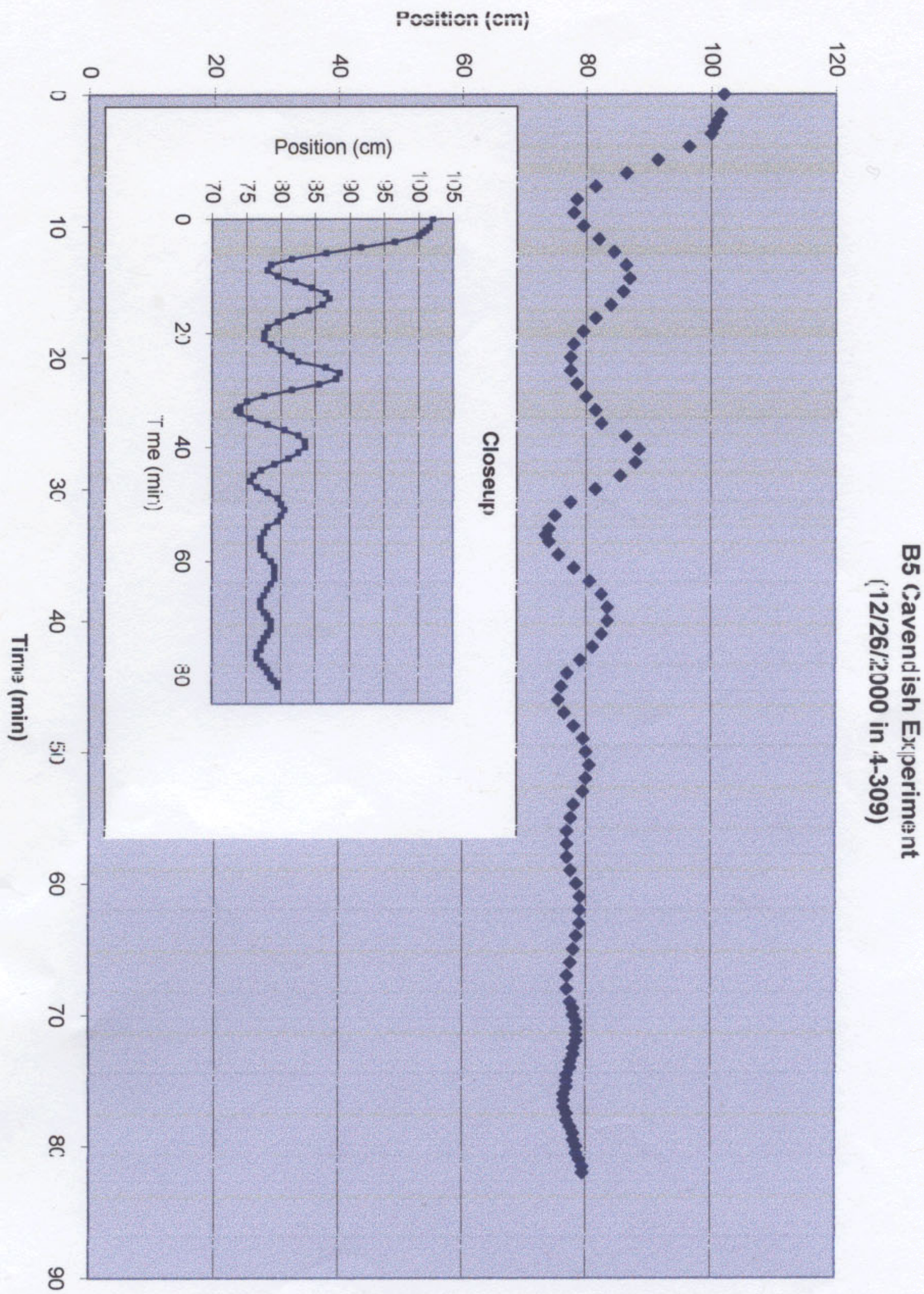


Fig. 8


B5 Cavendish Experiment
(12/26/2000 in 4-309)
Position (cm)
Time (min)
Closeup
Position (cm)
Time (min)

B5 CAVENDISH

B5

period	602 seconds	Inertia	0.000078 kg*m^2	mass1	0.015
lambda	1000 seconds	k	8.4969E-09 N*m/rad	mass2	1.5
dt	0 seconds	pi	3.14159265	Length	0.1
zero	48 mm	G	6.67E-11 m^3/(kg*s^2)	Distance	2
zerosc	6 mm	Angle	0.031 rad	Radius	0.0475
amplitude	55 mm	Expected Dx	0.067 m	Shift	0.7
		Measured Dx	0.048 m		
		Ratio Meas./Exp.	72%		

Time	Displacement	Displacement(	Time(sec)	Theory		Zero
12:17	6	0	0.00	-7.00	49.00	48
12:19	44	38	120.00	32.73	27.75	48
12:20	74	68	180.00	61.92	36.94	48
12:21	92	86	240.00	82.79	10.32	48
12:23	85	79	360.00	79.32	0.10	48
12:25	44	38	480.00	38.03	0.00	48
12:27	25	19	600.00	17.82	1.39	48
12:29	46	40	720.00	39.09	0.82	48
12:31	73	67	840.00	66.79	0.04	48
12:33	71	65	960.00	65.44	0.19	48
12:35	49	43	1080.00	42.90	0.01	48
12:37	38	32	1200.00	31.45	0.30	48
12:39	49	43	1320.00	42.82	0.03	48
12:41	64	58	1440.00	58.15	0.02	48
12:43	64	58	1560.00	57.70	0.09	48
12:45	52	46	1680.00	45.41	0.35	48
12:47	46	40	1800.00	38.93	1.15	48
12:49	51	45	1920.00	45.00	0.00	48
12:51	58	52	2040.00	53.47	2.17	48
12:55	54	48	2280.00	46.69	1.71	48
13:02	57	51	2700.00	51.68	0.46	48
13:04	56	50	2820.00	49.31	0.47	48
13:08	51	45	3060.00	45.76	0.58	48
13:12	54	48	3300.00	50.02	4.06	48
13:14	54	48	3420.00	48.76	0.76	48
13:16	53	47	3540.00	46.83	-0.17	48
13:19	53	47	3720.00	47.43	0.43	48
13:20	53	47	3780.00	48.23	1.23	48

Bolek Wyslouch Fall Term 1993 8.01

B5 THE CAVENDISH EXPERIMENT B5

DYNAMICS - Gravitational Forces

r = 4.65 cm

m = 1.5 kg

m = 0.015 kg

l = 10 cm

L = 19.7 m

$\Delta s = L.\theta$

k = 8.5 H 10^{-9} N^{-m}/rad

T ~ 10 min

$$\Delta s = \frac{4lLGmM}{kr^2}$$

$$= \frac{4 \times 0.10 \times L \times 6.672 \times 10^{-11} \times 0.015 \times 1.5}{8.5 \times 10^{-9} \times (.0465)^2}$$

$\Delta s = 0.0327L$ (m)

$(\Delta s)_{th} = 64$ cm

$(\Delta S)_{exp} = 88.5$ cm

Cavendish Exp.

Procedure:

Release small lead balls by unscrewing the two holders underneath them. Level lens bench so that the wire of the torsional pendulum does not hit anything. Place the large lead balls on their supports and make sure the wire still does not hit anything. Reflect the laser light off the mirror so that the reflected beam lies on the opposite wall of the lecture hall. Disturb the pendulum so that the small balls oscillate at full amplitude, i.e., so that they gently hit the glass wall on either side of the enclosure. Record that full swing amplitude on the opposite wall by using tape markers. Next, find the center of these two marks on the wall and mark it with a strip of color tape.

The next step is to try to adjust the pendulum, with the large lead balls in the center position, so that its zero point lies as close as possible to the center of the extrema marked earlier. In order to accelerate the dampening of the pendulum, one can use the small horseshoe magnet to repel the small lead balls in the desired direction. The period of the pendulum is 10 mins. When the pendulum is swinging freely (no magnets) the time between each half-cycle, from one extremum to the other, is very close to 5 min. This can be used to guess when the pendulum will reverse its direction and, therefore, will help in marking the turning points.

→

Cavendish Exp.

Procedure (Cont.) B5

When the pendulum has come to rest, mark the new equilibrium position. This will be the zero for the experiment. Next, turn the lead balls all the way to one side, so that they are (almost) touching the glass wall of the enclosure. This will set the pendulum moving in one direction. Repeat the dampening procedure described earlier to find the new equilibrium position. The pendulum is now ready for class.

At the beginning of class, the lecturer will move the large lead balls completely to the other side and, at the end of the lecture period, will mark the final equilibrium position. He will then measure the distance between the two rest positions corresponding to the large lead balls being one way or the other and use that to determine the value of G.

Cavendish Exp.

B5

Equipent Needed:

- Cavendish Apparatus
- Lens bench w/ adjustable legs (screws) so that it can be levelled.
- 1 lens holder
- 1 Table clamp
- 1 short rod
- 1 90° clamp
- Laser
- many lead bricks to stabilize the cart
- small horseshoe magnet to dampen tortional pendulum
- 2 meter stick, color tape, duct tape.
- Stopwatch

- Set Up:

Set up Cavendish apparatus and laser on white cart at one end of lecture hall. Direct reflected beam of laser light to opposite wall of lecture hall.

Cavendish Exp.

B5

$r = 4.65$ cm (balls center to center)

$M = 1.5$ kg

$m = 0.015$ kg $\quad k = 8.5 \times 10^{-9}$ N-m/rad

$\ell = 10$ cm $\quad T \sim 10$ min

$L = 19.7$ m

$\Delta s = L \cdot \theta$ ~~[illegible]~~

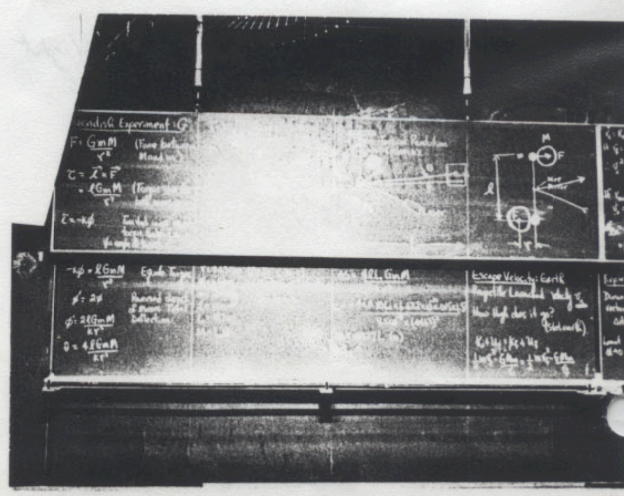
$$\Delta s = \frac{4 \ell L G m M}{k r^2}$$

$$= \frac{4 \times 0.10 \times L \times 6.672 \times 10^{-11} \times 0.015 \times 1.5}{8.5 \times 10^{-9} \times (.0465)^2}$$

$\Delta s = 0.0327 L$ (m)

$(\Delta s)_{Th} =$ ~~8~~ 64 cm

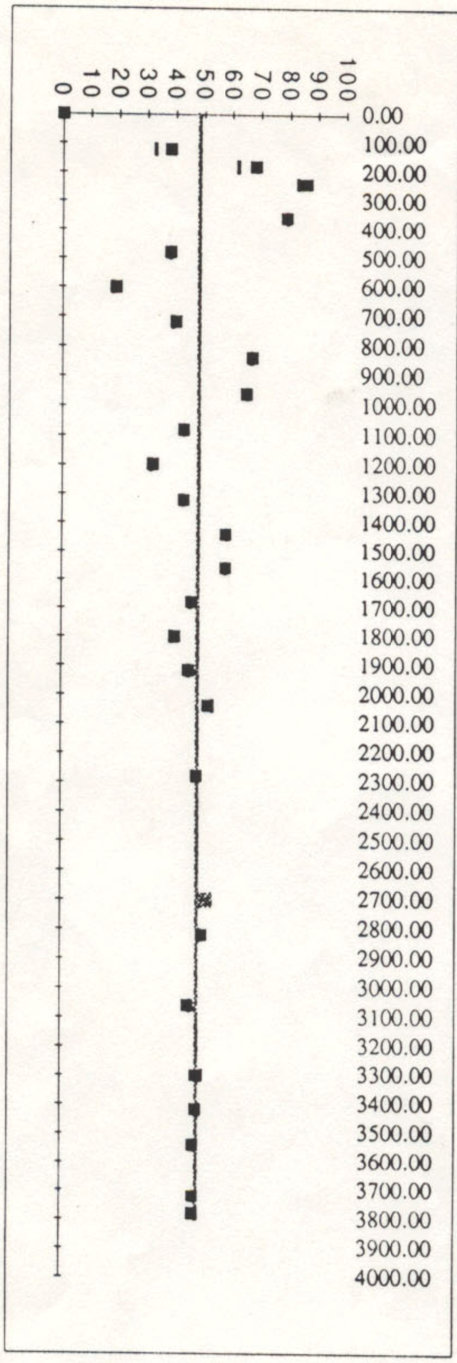
$(\Delta s)_{exp} = 88.5$ cm

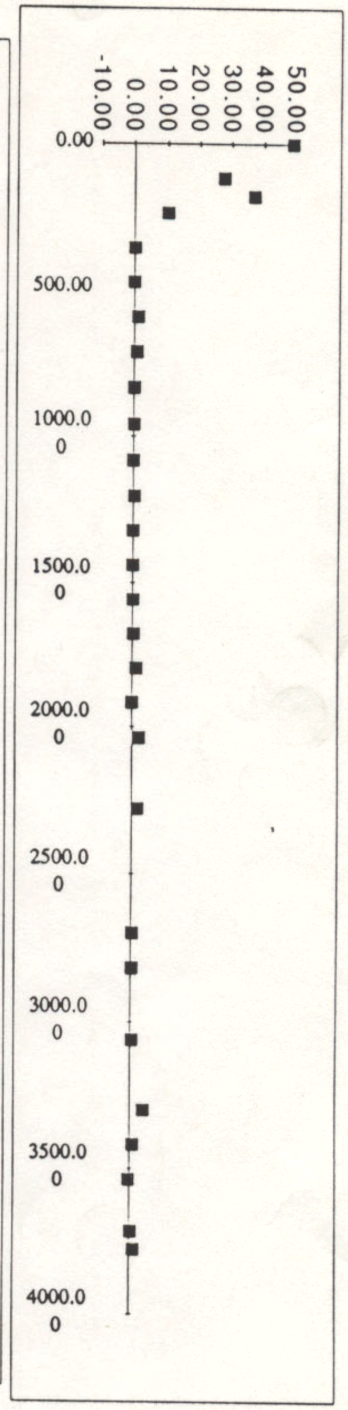


B5 Supplemental Information for B5 Cavendish Experiment

CAVENDISH

B5





Class		
Minutes	45	
Seconds	2700.00	51.21

Difference 3.21

Bolek Wyslouch 1993 8.01

Gravitation Torsion Balance

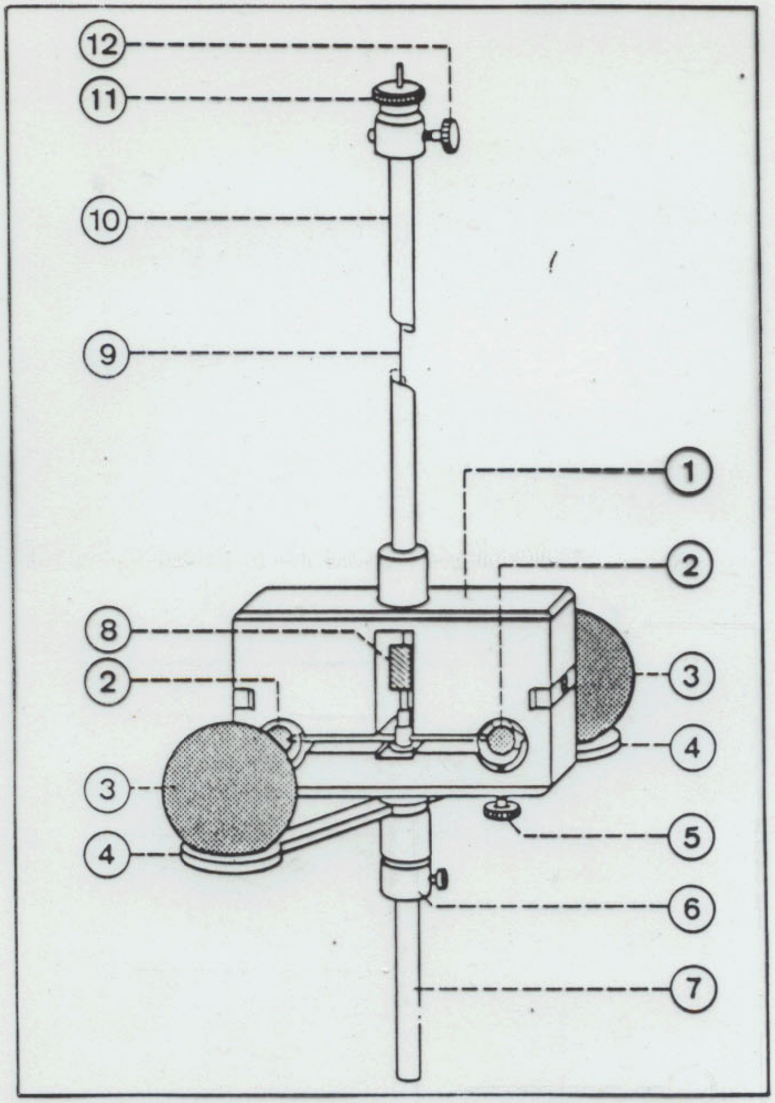


Fig. 1 Standard equipment of gravitation torsion balance (332 10)