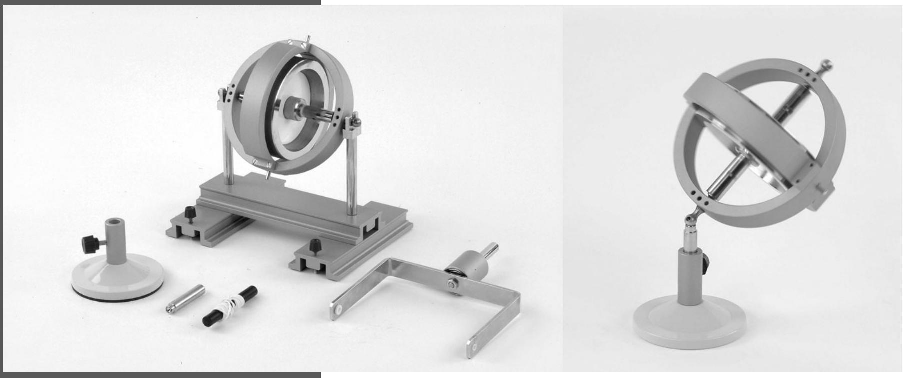
Manual

for

Gyroscope DM354-1K



simple, fast, safe

Introduction

This gyroscope is supplied with all accessories required for demonstrating in a simple yet effective manner all of the properties of a symmetric gyroscope.

When considering gyroscopes, one is often reminded of the spinning tops children play with, bodies capable of fascinating sorts of motion. The physical principles utilized even by spinning tops are not easy to explain, though. Such tops often have an asymmetric shape, a specially designed pivot or their weight is distributed unevenly.

Working with a symmetric gyroscope can be a first step toward developing an understanding of the phenomena behind gyroscopes and tops. The experiments described in this experiment guide aim at providing such an understanding. These phenomena include the basic behaviour of a free gyroscope as well as precession as seen in a gyroscopic on which external forces act.

In addition, a number of observations will be made pointing out the everyday situations in which symmetric gyroscopes serve an important function.

Immediately following the ensuing description of the apparatus, these experiments are described fully in the present guide:

1. Free Gyroscope
1.2 Basic characteristics of a free gyroscope
1.3 Application: gyrocompass

2. Precession of a gyroscope
2.4 Suspended gyroscope
2.5 Gyroscope spinning on a point
2.6 Gyroscope spinning on a hand

Introduction

<u>Background information from physics:</u>

It has already been mentioned that the phenomena displayed by the gyroscope are by no means to be attributed to simple physical principles. The present supplementary guide does not at all aim to discuss these complex physical principles in detail. However, mention will be made time and again of the physical theory underlying the particular experiment being observed.

The law of the conservation of angular momentum within a closed system is the basic physical principle underlying the rotation of rigid bodies. The conservation of angular momentum will play an intrinsic role in understanding the motion displayed by gyroscopes. The following applies:

$$\boxed{\vec{L}_{total} = const.}$$

In order to determine angular momentum of any given rotating body, it is necessary to apply the definition of angular momentum. The following applies:

$$\boxed{\vec{L} = I\vec{\omega}}$$

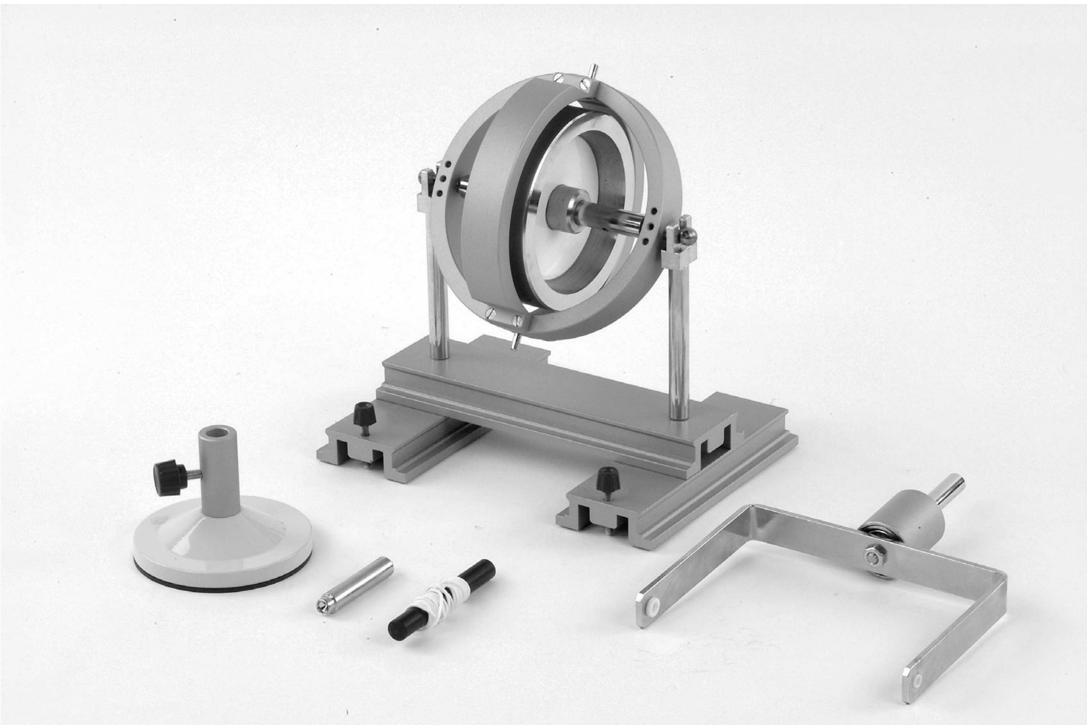
I … the body's rotational inertia about the axis
$\vec{\omega}$ … the body's angular velocity

These relationships, touched on just briefly here, will help explain what is occurring in the following experiments. No attempt is made here at an exhaustive and precise explanation in physical terms of the subject of *conservation of angular momentum*, since it is treated in depth in most physics textbooks.

Description of Apparatus

Material included for performing experiments:

1 Gyroscope, 1000 g, set no. DM354-1K consisting of:
1 U-bracket
1 Support base for gyroscope
1 Round base for gyroscope
1 Rod used as a bearing with a point and a cup at the ends
1 Cord
1 Allen wrench
1 Tube of grease



Description of Apparatus

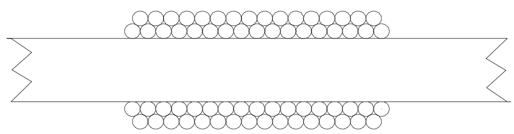
1. Use of a padded surface:

It has already been mentioned that the gyroscope has a stable frame. Nonetheless, it is advisable to do experiments with the gyroscope on a padded surface. Two thick layers of corrugated cardboard or a blanket folded several times can provide such a surface. In the event that the gyroscope "crashes" (such things do occur!) and is not able to be caught in time, it may make noticeable depressions in the table or even fall on one of its own brass bearings (both of the bearings protrude from the frame). The latter is certainly not good for the gyroscope and would most probably have a negative effect on its ability to rotate.

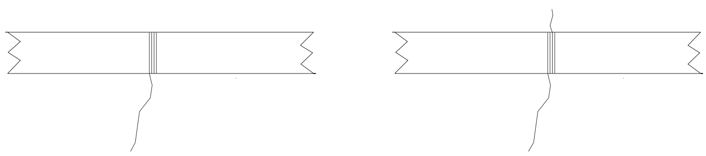
2. Starting the gyroscope:

The gyroscope is started using the specially designed support base provided. The gyroscope is first laid on the support base with the two brass pins, which protrude from the frame and also serve as bearings, resting in the base. This is the proper position for storing the gyroscope, especially when it is no longer being used yet still rotating. The gyroscope is started using the cord provided. With one end of the cord inserted in one of the small holes in the gyroscope axis, wind the entire length of the cord around the axis. The gyroscope may then be made to rotate by pulling on the cord with a strong but even application of force.
Three items deserve attention when starting the gyroscope:

1. The cord needs to be wound around the axis evenly. This is a cross-sectional view of the axis with a cord wound about it in the best possible manner:



2. When threading the cord through the hole in the axis, take care that the cord does not protrude from the other side of the hole. Otherwise the cord may become wound up again after unwinding completely.



Description of Apparatus

3. When pulling the cord, the gyroscope needs to be held in place very firmly by means of the support base. The way of holding the gyroscope is shown here:

3. Caring for the gyroscope:

Generally speaking, the design of the gyroscope ensures that it runs very smoothly. It is nonetheless necessary to lubricate the bearings once it has been used for a while. It is in any case necessary to adjust the bearings as soon as they begin to make noises (the whole gyroscope seems to “hum”).

To do this, first loosen the Allen head screws holding the brass bearings in place using the wrench provided. The brass bearings may then be adjusted by screwing them in or out to the best possible position. The axis should be “firmly” seated. However, avoid screwing out the bearings to the point that they slow down the gyroscope. Afterwards, tighten the two Allen head screws in order to fasten the brass bearings in place.

Exp. 1 Free Gyroscope

A *free gyroscope* is a symmetric gyroscope mounted or suspended in such a manner that no forces can influence it. There are two ways of mounting or suspending a gyroscope so that it is free from external forces. One method is to mount a specially shaped gyroscope to rotate around its centre of gravity and the other is to suspend the gyroscope from gimbals. This second technique for creating a free gyroscope, shown in the picture below, can be applied using the materials included in the set.

1.1 Basic characteristics of a free gyroscope

Among the accessories you will find a u-bracket with which the gyroscope can be suspended from gimbals and thus with no external forces acting on it. This arrangement demonstrates the characteristics of a free gyroscope.

What you need:
- the gyroscope
- the support base and the cord for starting the gyroscope
- the u-bracket
- the round base

Experiment: First remove the rotating gyroscope from the support base used to start it (see the description of the apparatus to find out how to start the gyroscope) and place it in the u-bracket fastened in the other support base. Pick up the base of the u-bracket and move it around the room in any direction. In this way all possible translational and rotational movements can be attempted.

Result: The axis of the gyroscope maintains its position and direction of rotation no matter how the position of the bracket changes.

Exp. 1 Free Gyroscope

Tips and tricks: When doing this experiment, one should keep in mind that the bearings are not completely friction-free. The bearing at the centre of the u-bracket in particular produces quite a large amount of friction when held in certain special positions. This is the case especially when the axis of the bearing is inclined at an extreme angle so that the entire weight of the gyroscope is suspended from the bearing. The following may be done so that the effects of friction do not disturb the motion of the free gyroscope during demonstrations:
When moving the bracket, perform movements very slowly and evenly.
Avoid moving it in such a manner that the axis of the gyroscope points even briefly in the same direction as the pivoting axis of the brass bearing.

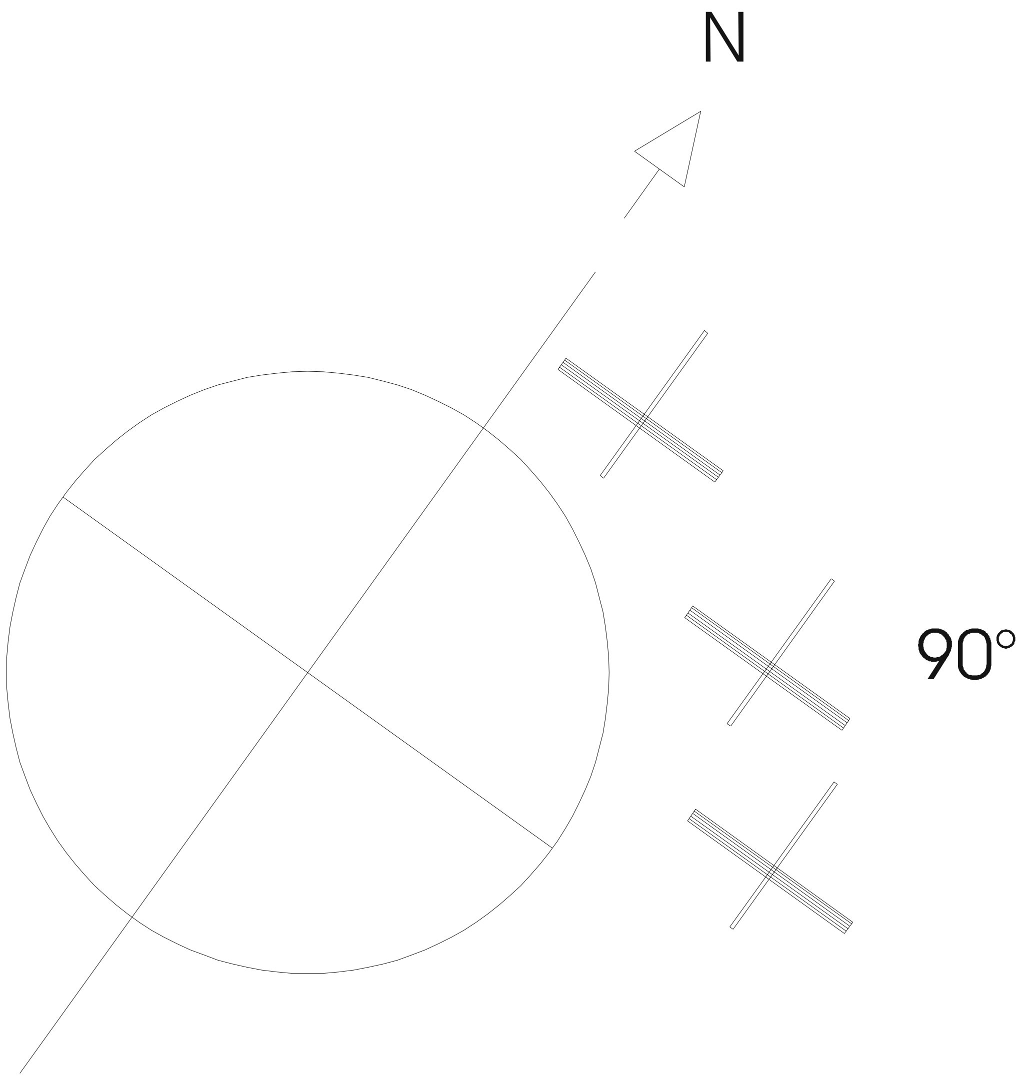
Physicist's perspective: Like most phenomena associated with the gyroscope, the property of the free gyroscope demonstrated here is attributed to the conservation of angular momentum in a closed system. Due to the special method of suspending the gyroscope, through which no external forces can act on it, it may be seen here as a closed system. Angular momentum is expressed as a vector, meaning it has a magnitude and a direction. As long as angular momentum is conserved, it maintains its magnitude and direction as well. This explains why the direction of the axis of the gyroscope is maintained as the position of the bracket from which it is suspended changes.

Exp. 1 Free Gyroscope

1.2 Determining geographical latitude

What you need:
- the gyroscope
- the support base and the cord for starting the gyroscope
- the u-bracket
- the round base
- a globe
- a plumb line

Experiment: Once the gyroscope has been set into motion, adjust its axis so that it points parallel to the earth's axis, that is, the globe's. With the aid of a plumb line, the free gyroscope may now be used to determine the position of geographical latitude at present. The plumb line forms a certain angle (90° - φ) with the axis of the gyroscope, when the gyroscope, or more precisely its centre of gravity, is situated at φ degrees geographical latitude. This relationship is illustrated graphically in the following diagram.



Exp. 1 Free Gyroscope

<u>Application:</u> Navigating ships and airplanes would be unthinkable without this particular property of the free gyroscope. A free gyroscope similar to the one used in the experiment described here is built into the so-called gyrocompass. A gyrocompass also contains a large number of additional mechanical parts which, however, only serve to improve the workings of the free gyroscope, in particular ensuring that it works precisely. Basically speaking, a gyrocompass works in exactly the same manner as the one used in this experiment. Often it also includes a device to enable the degrees of geographical latitude to be read off directly.

Yet, one question remains open: how can the axis of a gyroscope, particularly when it is enclosed in a compass case, be adjusted so that it is exactly parallel to the earth's axis?

This question is easy to answer when one briefly considers the matter of conservation of angular momentum. As has already been mentioned, angular momentum is conserved in a closed system. Yet, since by means of its frame it is connected to the earth, representing a rotating system of reference, the gyroscope or gyrocompass cannot be viewed as a closed system. Thus, the earth's rotation must have some effect on the behaviour of the gyroscope. This effect is the basis for a rather astonishing property of a free gyroscope appropriately mounted within the earth as its reference system: ***The gyroscope automatically adjusts its position so that its axis is always parallel to the earth's. Once the gyroscope has found this position, it remains in it permanently.*** This means that a gyrocompass calibrates itself in effect, righting itself automatically.

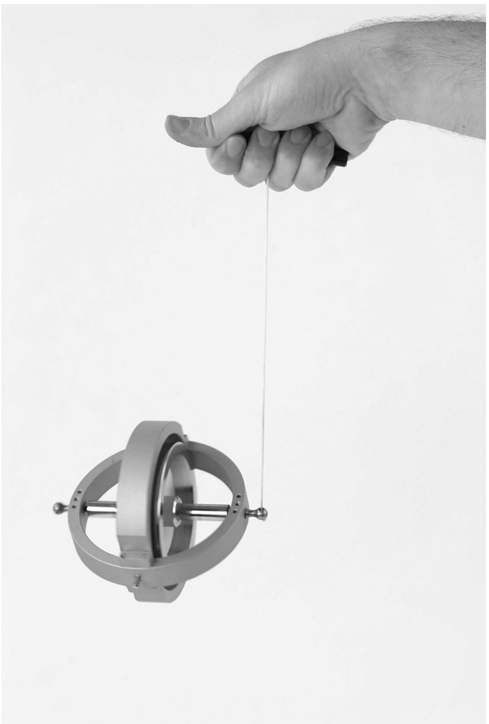
Exp. 2 Precession of a Gyroscope

In contrast to Exp. 1, in the following the basic behaviour of a gyroscope on which external forces act is demonstrated. This refers to a gyroscope which, by virtue of the way it is mounted, cannot be considered a closed system, and thus it is subject to external forces. Hence, a gyroscope on which external forces act is neither mounted to rotate around its centre of gravity nor on gimbals. These two methods for mounting a free gyroscope are described in Exp. 1.

2.1 Suspended gyroscope

What you need: - the gyroscope
- the support base and the cord for starting the gyroscope

Experiment: Once the gyroscope has been set into motion, suspend it from the cord provided with the set as displayed in the picture below. Stabilize the gyroscope initially using your free hand. Then release the gyroscope and observe what occurs.



Result: The gyroscope does not fall to the ground as one might expect. Initially, the axis moves along approximately the same plane within its orbit. The cord and the axis move together, maintaining the same angle to each other that they had before the gyroscope was released.

Exp. 2 Precession of a Gyroscope

2.2 Gyroscope spinning on a point

What you need: - the gyroscope
- the support base and the cord for starting the gyroscope
- the round base and the rod with a point and cup at the ends

Experiment: Insert the rod into the round base and fasten it in place. Once the gyroscope has been started, place it on the corresponding end of the rod (i.e. “cup to point” or “ball to cup”).

Result: The gyroscope does not fall to the ground. While moving, the axis of the gyroscope describes a so-called precession cone.

Exp. 2 Precession of a Gyroscope

2.3 Gyroscope spinning on a hand

What you need: - the gyroscope
- the support base and the cord for starting the gyroscope

Experiment: Place the rotating gyroscope on the palm of your hand.

Result: The axis of the gyroscope does not drop immediately. The gyroscope "dances" on your hand until it begins to lose "power", the radius of the circle described by the point of the gyroscope at the upper end becoming increasingly larger.

Exp. 2 Precession of a Gyroscope

<u>Tips and tricks:</u> Due to the unavoidable effect of friction, the angular momentum of the gyroscope weakens in time and gravity finally “wins out” – the axis then drops. This effect should by all means be explained! The precession of a gyroscope may, on the other hand, may be sufficiently demonstrated by repeating Experiments 2.1 to 2.3 several times in sequence.

<u>Physicist’s perspective:</u> The phenomenon observed in Experiments 2.1 to 2.3 serves as the basis of the type of motion known as *precession*.

The gyroscope used in this case is a symmetric gyroscope. One property of such a gyroscope is that its axis always maintains its direction in space, regardless of how its surroundings move. This is, of course, only true as long as no external forces act on the gyroscope or its axis; this is, for example, the case when the gyroscope is mounted on gimbals (this form of suspension makes any gyroscope into a free gyroscope).

It has already been seen that, when an external force acts on the gyroscope axis, it moves at right angles to the direction of the force acting on it.

This phenomenon may be explained briefly as follows:

A symmetric gyroscope rotates and thus has a certain angular momentum $\vec{L}$. When a force $\vec{F}$ acts on the gyroscope axis, a certain amount of torque $\vec{M}$ also acts on the gyroscope. The interaction of torque $\vec{M}$ and angular momentum $\vec{L}$ result in angular momentum in a different direction $\Delta\vec{L}$ which causes the gyroscope to move in the direction described above.