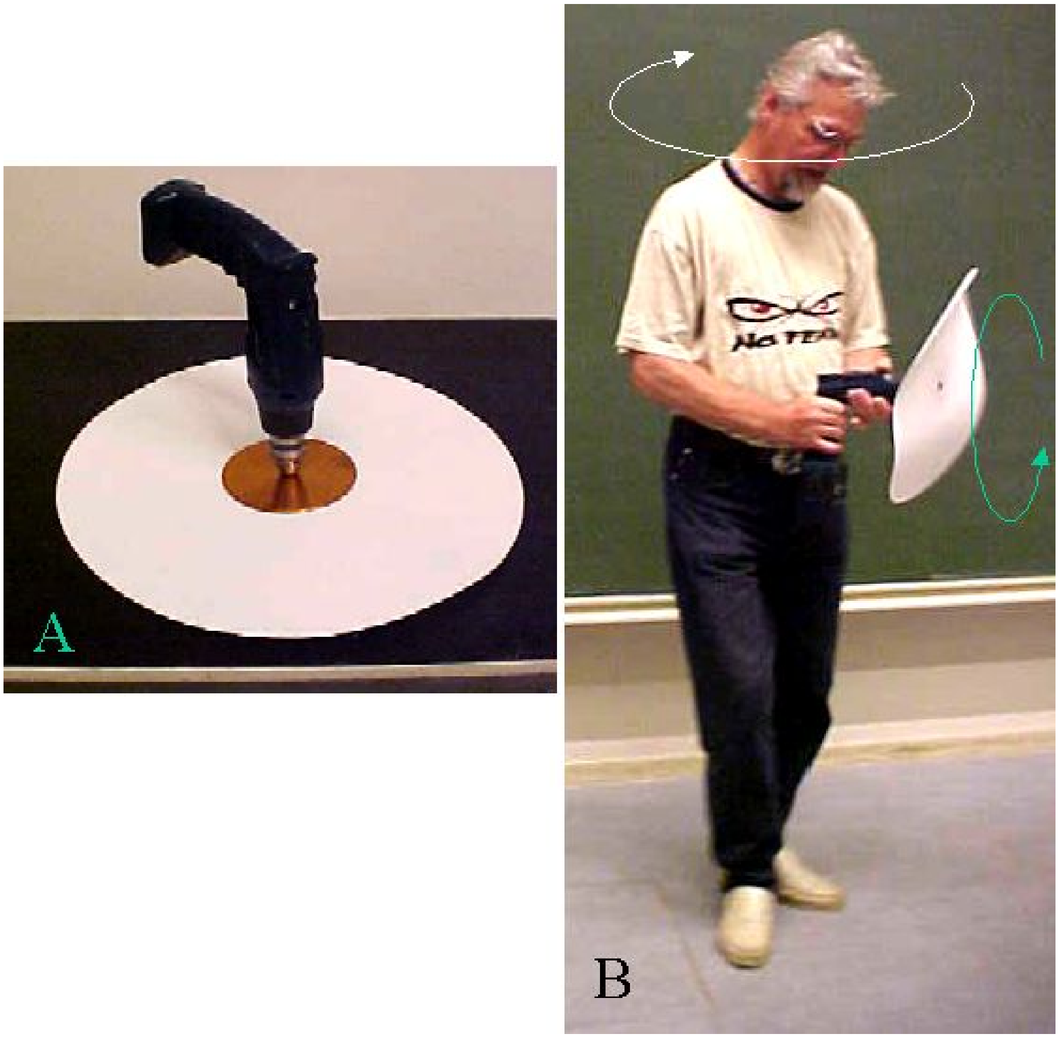
Coriolis (2)

Aim: To show a rather complicated rotation and how Coriolis force and centripetal (or centrifugal) forces can explain the situation.

Subjects: 1E20 (Rotating Reference Frames)
1E30 (Coriolis Effect)

Diagram:



Equipment:

- Hand drilling machine
- Sheet of thick paper, cut circularly; diameter=50cm.
- Round metal plate, diam.=15cm, with a pin in its centre.
- Double sided adhesive tape.

Safety

- Sometimes in this demonstration we use a drilling machine connected to the 220V mains. When turning round as demonstrator, mind that you do not get entangled in the cord.

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Presentation: The sheet of paper is stuck to the round metal plate with pieces of double sided adhesive tape. Then this combination is fixed in the chuck of the hand drilling machine (see Diagram A). The demonstrator holds the drilling machine with its spindle horizontal and starts it.
First, the demonstrator stands still and the circular sheet of paper turns in a plane. Then the demonstrator turns around his body-axis and clearly can be seen that the circular plane is distorted: the upper and lower part bend in opposite directions, one part towards the demonstrator, the other away from him (see Diagram B). When the demonstrator turns the other way round, the upper - and lower distortions also change direction. The same happens when he makes the drilling machine rotate into the other direction.
We use this demonstration to challenge the students to explain the observed deformation of the paper sheet.

Explanation: 1. Explaining it from within the rotating frame of reference of the demonstrator:
The demonstrator turns round, so he is in a rotating reference frame. In this rotating reference frame every part of the sheet of paper has a specific velocity (see the four $\vec{v}\,'$'s drawn in Figure 1).
In a rotating reference frame every object moving with a certain velocity has to deal with Coriolis-force: $\vec{F}_{cor} = -2m\left(\vec{\omega}\times\vec{v}\,'\right)$ and with centrifugal force: $F_{cf} = -m\vec{\omega}\times(\vec{\omega}\times\vec{r})$,
(r being the radius from the axis of the demonstrator to the piece of paper considered). We consider the four indicated parts of the rotating paper disk (see Figure1):

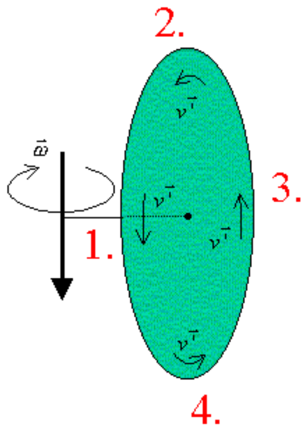

Figure 1

1. v' parallel to ω, so $F_{cor}=0$; $F_{cf} \neq 0$.

2. v' perpendicular to ω; direction of F_{cor}: see Figure 2A. This F_{cor} adds to F_{cf}. In general $F_{cor} >> F_{cf}$, so there is a large F pointing outwards, in magnitude almost equal to F_{cor}. (See the result on point 2. in Figure 3).

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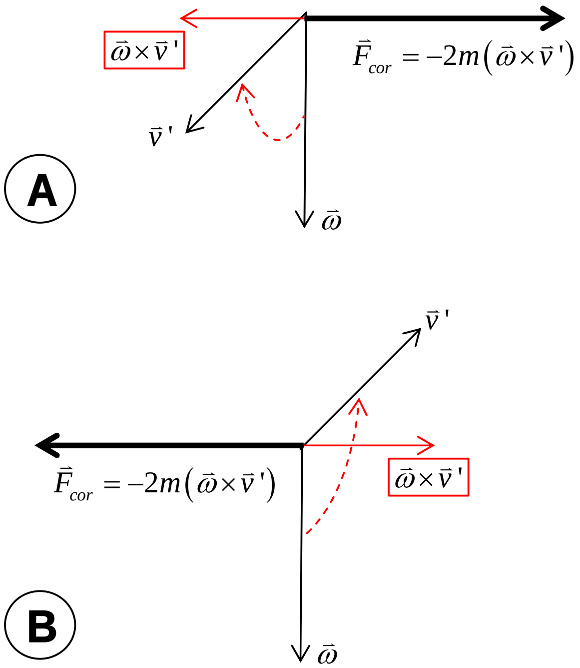

Figure 2

3. -v' parallel to ω, so $F_{cor}=0$; $F_{cf} \neq 0$

4. v' perpendicular to ω; direction of F_{cor} see Figure2 B. $F_{cf} \neq 0$. F_{cor} is opposing F_{cf}. In general $F_{cor} >> F_{cf}$, so there is a large F pointing inward, in magnitude almost equal to F_{cor}. (See the result on point 4. in Figure 3.)

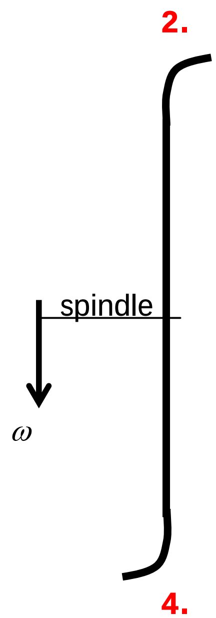

Figure 3

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<u>2. Explaining it from the outside:</u>
In Figure 1 the whole piece of paper turns around the axis of the demonstrator. The magnitude of v' hardly changes when the demonstrator starts turning with ω around his axis (see the red arrows in Figure 4): We consider v' remaining constant in magnitude.

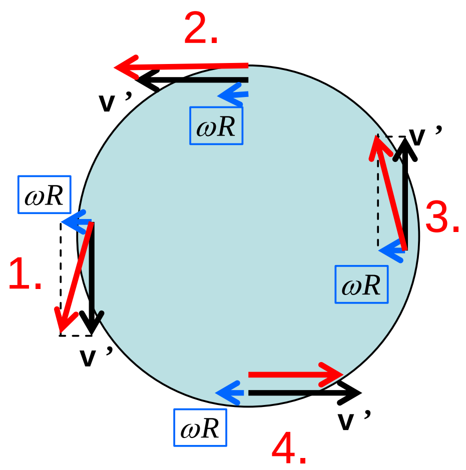

Figure 4

But due to ω of the demonstrator v' in position 2. and 4. **changes direction** appreciably. **Forces are needed for that**. Figure 5 shows how v' changes direction in position 2. and in position 4.

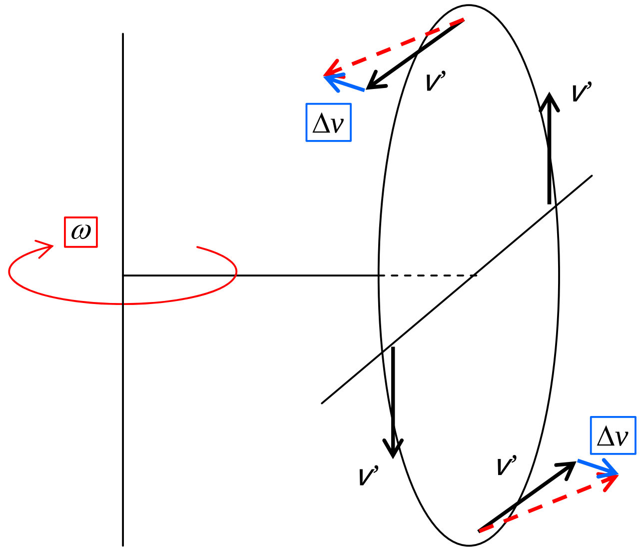

Figure 5

The two Δv's in that Figure 5 also show the directions of the forces needed for that. But there are no such forces applied to these positions of the paper since the paper is slack in its material substance. To create this force in the paper a deformation is needed. For that reason the upper part will bend outward and the lower part inward. These directions of deformation correspond with the deformation shown in Figure 3.

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3. Explaining it with ω-vectors.

This is the "easiest" explanation.
There are two ω-vectors in this demonstration: ω of the paper disk and ω of the demonstrator. In the demonstration these two add together (see Figure 6) to the green ω_{TOTAL}. The rotating disk will orientate itself to this new rotational vector.

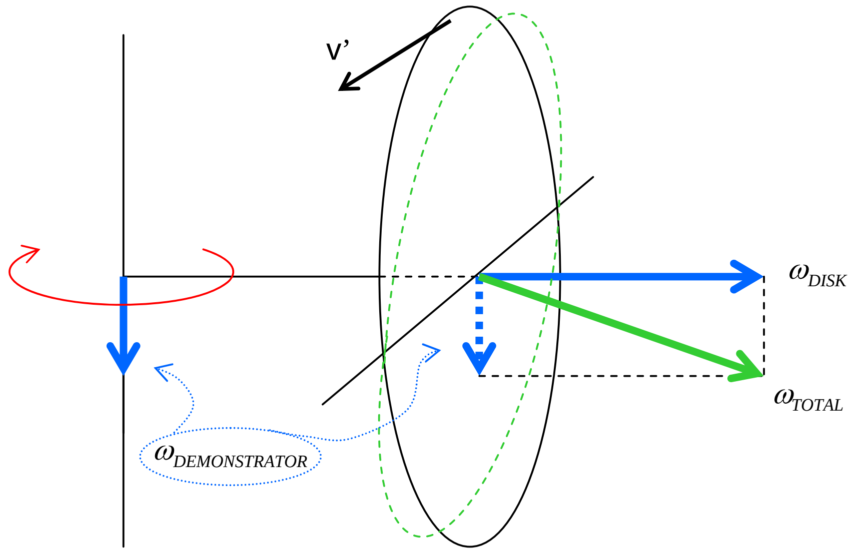

Figure 6

(In stead of using $\vec{\omega}$-vectors in this explanation you can also use $\vec{L}$-vectors.)

Remarks:
- When preparing the demonstration, find the right speeds for the drilling machine and your own rotation to get the effect you want.

Sources:
- Magnus, K., Kreisel, pag. 239-240.
- Mansfield, M and O'Sullivan, C., Understanding physics, pag. 182.
- McComb,W.D., Dynamics and Relativity, pag. 137-145.
- Roest, R. Inleiding Mechanica, pag. 197-202 and 205-210.