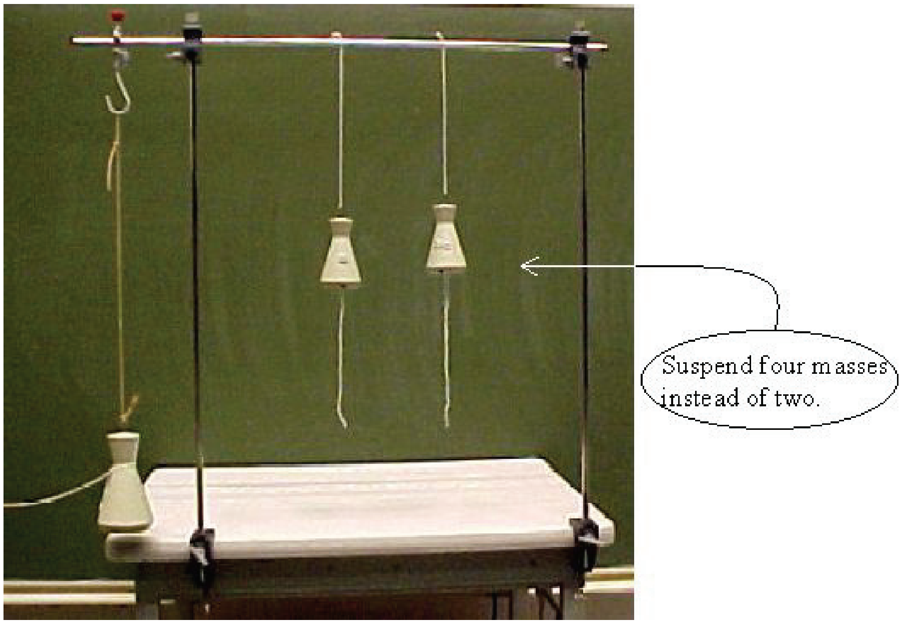
Pulling a thread

Aim: To use Newton's second law in order to explain a surprising demonstration.

Subjects: 1G10 (Force, Mass, and Acceleration)

Diagram:



Equipment:

- Mass of 5kg.
- 4 identical masses, 1kg each (see Remarks).
- Thin cotton thread.
- A bar to hang the masses.

Safety:

- Mind the falling weights! You can put a foam cushion under the weights.

Pulling a thread

Presentation: **1.** The mass of 5kg is suspended at a strong thread. By means of a thin cotton thread it can be displaced horizontally. Slowly pulling shows this. But when a jerk is given, the thin cotton thread breaks.

2. By means of thin thread, the two masses of 1kg are hung on to the bar. On the bottom-side of each mass a free hanging thread is tied. Ask the students which thread will break, the upper or the lower, when we increase slowly the pulling force on the bottom thread. Slowly pull the lower thread of one mass. This will cause the upper thread to break. Then ask the students which thread will break when we increase the pulling force on the lower thread very fast. Pull the lower thread on the second mass rapidly. This time the lower thread will break.

Explanation: **1.** The tension (T) in the thin thread equals the force applied to the thread: $F=T$. This force accelerates m (see Figure 1). A jerk means that a is high; a high F ($=ma$) is needed for that. So the tension in the thread will be high and the thread can break.

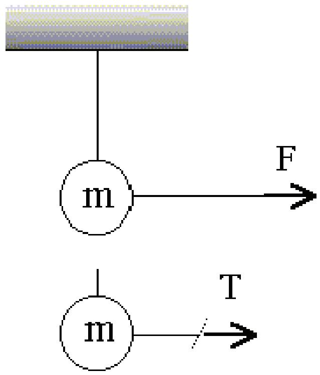


Figure 1

2a. A *general explanation* is that when we increase the pulling force slowly, a low acceleration is implied on to the mass. The mass can follow this acceleration, giving a stretch to the upper thread. The upper thread experiences also the weight of the mass, so this will be the thread to break. When we try to give the mass a high acceleration, the inertia of the mass cannot follow our hand so quickly: It stays behind. The thread between our hand and mass will experience a large stretch and breaks. To the upper thread nothing happens, because the mass is not moving downwards now. The top thread only experiences the weight of the mass, like it did already.

2b. An *analytical explanation*, using Newton's second law gives still more insight. The forces acting on m are T_1, T_2 and mg (see Figure 2). T_1 is the tension in the upper thread. The tension in the lower thread is T_2. The acceleration a that m obtains can be determined by: $ma=T_2+mg-T_1$
It follows: $ma-mg=T_2-T_1$ or $m(a-g)=T_2-T_1$

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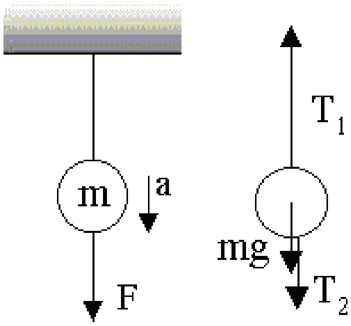

Figure 2

As long as $a < g$, then $T_2 < T_1$ and the top-thread will break. But when $a > g$, then $T_2 > T_1$ and the bottom-thread will break.

This last explanation shows the power of Newton's second law: Now it is possible to say something about the acceleration *a*, that determines what will happen (which thread will break). (A student asked: what will happen when $a=g$?)

Remarks:

- We suspend 4 masses in order to perform the demonstration twice (without tedious knotting).
- Presentation 1 can directly be referred to the common experience that when pulling a damaged car by another car, the pulling car should start slowly otherwise the pulling rope will break.
- A variation to presentation 1 is attaching a thread to a mass and slowly pulling upward, lifting the mass. Repeating this with a jerk will break the thread.
- In a more sophisticated analysis, also the elasticity and lenth of both cords should be taken in account (see AJP- and PT-articles mentioned in Remarks).

Sources:

- Ehrlich, Robert, Turning the World Inside Out and 174 Other Simple Physics Demonstrations, pag. 30.
- Friedrich, Artur, Handbuch der experimentellen Schulphysik, part 2, Mechanik der festen Körper, pag. 85.
- Freier, George D. and Anderson, Frances J., A demonstration handbook for physics, pag. M16.
- Sutton, Richard Manliffe, Demonstration experiments in Physics, pag. 46-47.
- American Journal of Physics, pag. 860-862 (Vol. 72-7; 2004).
- The Physics Teacher, pag.504-507 (Vol. 34; Nov. 1996).