

## Physics ... not only with Chalk and Blackboard

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### Abstract

*The purpose of this article is to describe several simple experiments one can do with a straw, a paperclip and a piece of thread. And moreover, to indicate how, using such simple means, one can do a physics “show” where everybody in the audience can use these tools “to investigate physics around us (life, the Universe and everything :-)”.*

*The less ambitious goal is to remind these experiments to those who participated at such “show” at GIREP 2004 conference.*

### Introduction – how this all started

Let me begin in a bit personal manner and describe how the whole idea of the “show” began.

Our Faculty organizes a “Day of Open Doors” for high school students each year. One part of that is a main lecture for all, say, five hundred or more participants. And, for 2004, it was decided that the lecture should be given by a person from Department of Physics Education – namely by me.

Now, every specialist popularizes his own area at such lecture. A geophysicist speaks about earthquakes, seismographs etc. An astronomer about stars. Both of them have a lot of fine photographs and can persuade the audience that their teams work at the cutting edge of the science. One should come up with something interesting and popular! Of course, I could speak about black holes (general relativity was my area in the past) but similar theme was presented several years ago and, to be frank, I am not fluent in the latest development in this field. Moreover, one should popularize his own current area of interests. But – could I speak to high school students about **education**? It seemed absurd to me.

Gradually, the idea occurred that I may present some simple experiments and show (at least slightly) how they are related to the themes of “high physics”. But will the students listen? Or will they rather fall asleep while watching passively some distant presentation? Anyway, in good education students should be active!

And this was the main point. The audience should be active. So, **everybody in the audience should do his or her own experiments!**

This idea seemed to be crazy enough to work but some “technicalities” still remained. Which experiments to

choose? And where to find enough sets of experimental tools for five hundred or more people in the auditorium?

### 1 Our tools: straw, paperclip and thread

One thing was clear. The tools should be small. And, of course, cheap. So we should choose them from things we meet in an ordinary life rather than to use equipment from a physics lab. And there should be just a few of them while still enabling to do a variety of experiments.

You may perhaps find many other things. But, after some rather long thinking and experimenting, I ended up with just three very simple tools: a plastic straw, a paperclip and a piece of thread (tied to the paperclip). It occurred to be possible to think up about twenty simple experiments with these tools. (Of course, “to think up” means in many cases to adapt older experiments, to combine ideas remembered from long-ago forgotten sources... – you all know that well.) Then, in a “pilot phase”, I presented these experiments in a very raw form to a group of physics teachers and university students and afterwards, utilizing the comments, I selected the experiments which then formed a core of the show.

What else should be done?

To specify the themes from “high physics” (or, at least, “university physics”) connected with simple experiments. To come up with sufficiently non-standard beginning to attract attention. (Just to start by saying “Dear students, take your paperclip and, please, do this simple experiment.” probably would not be enough for today’s young generation.) To choose music for that attractive beginning. To decide how to show the experiments to the whole auditorium to make clear how to carry them out... Etc. etc. And, last but not least: to solve the problem how to distribute those “sets of experimental tools” to all people in the audience.

With the help of keen collaborators this all proved to be manageable. And, in December 2003, we really did the show where about five hundred high school students experimented simultaneously using above-mentioned “tools”. The responses were rewarding – so, when asked, I decided to present similar “show” at GIREP 2004.

In following paragraphs I will briefly present just the ideas of selected experiments – and sometimes comment very shortly what can be mentioned in connection with them.

## 2 Simple start: minimum of potential energy, the centre of mass

Maybe the simplest experiment is to hold the thread on which the paperclip is tied. Of course, the paperclip hangs just below the suspension point. So we have found a *vertical direction* and simultaneously demonstrated the *minimum of potential energy*. (You see that such an experiment really requires an attractive introduction not to be perceived as something completely stupid. :-)

Then you can pretend that the result of this experiment is that the geometrical centre of the body hangs below the suspension point – and demonstrate that this is not always the case. A rod or a tube with a heavy mass in it near one of its ends will show it clearly. Of course, this is the *centre of mass*, which plays the role... Now you can show the old experiment of finding the centre of mass of the rod by putting the rod on two of your fingers and bringing the fingers closer to each other.

Is it possible to show it with our tools? Yes, with a straw. To shift the centre of mass from the geometrical centre of the straw just put the paperclip into one end of the straw.

## 3 Rotation: free axis and stroboscope effect

Hold the end of the thread by your thumb and forefinger. Then you can, by small motion of your fingers, let the thread spin with paperclip hanging at the other end. It enables us to do two other experiments.

If angular velocity of the rotating paperclip is sufficiently high you can mention that the paperclip tries to rotate around the axis corresponding to its maximum momentum of inertia (it is perpendicular to the longer side of the paperclip). It helps if you move the knot along the paperclip wire beforehand so that the paperclip hangs obliquely.

For another experiment let the paperclip hang perpendicularly to the thread. Rotating the paperclip before a TV set or CRT monitor you will see it standing in various positions. Changing the angular speed you can study a stroboscopic effect.

## 4 Weighting the Earth

To weight the Earth with our tools we will need to know something beforehand: its radius  $R$  and Newton gravitational constant  $G$ . Using 2<sup>nd</sup> Newton law and Newton gravitational law we can easily arrive at the formula  $M=(gR^2)/G$ . So, to weight our Earth it is sufficient to measure the gravitational acceleration  $g$ . This can be done by a pendulum, since its period  $T$  depends on  $g$ . For mathematical pendulum  $g=(4\pi^2l)/T^2$ , where  $l$  is the length of the pendulum.

As we can see, even at a show, for students or other interested people it is not hard to arrive at formulas mentioned above – or, at least, to accept them. And now, again, our tools may help.

A paperclip hanging on a thread is a pendulum. (Of course, a paperclip is not a mass point but...) The suspension point will be our hand. And for measurement of the length of our pendulum we can use the straw as a length etalon. For example, everybody in the auditorium can set the length of his or her pendulum from the suspension point to the centre of a paperclip equal to the length of the straw. In our case this length was 21 cm. (Which, by chance, equals to the famous wavelength of a hydrogen line at which in the past some people tried to find signals from extraterrestrial civilizations. :-)

To do a reasonably precise measurement you need lots of data, to take the average etc. In our case we can determine the average of period  $T$  in a simple and very “show-like” way. Ask people in the audience to start swinging of their pendulums at the same moment, to count ten periods – and then to shout. And stop the stopwatch at the moment of maximum shouting. This is quite fun for the audience, it really more or less averages the values and, moreover, if you would like to cheat a bit and to have the resulting mass precise to, say, four decimal places, you may announce any  $T$  you like :-).

I prefer not to cheat at all but rather to show a quick rough estimate of the result:  $\pi^2$  is nearly 10 and, for  $l=0,21\text{m}$ ,  $T$  measured is such that  $T^2$  just cancels with  $4l$ . It is really true, without any cheating! So,  $g$  is about  $10\text{m/s}^2$ . (No surprise, everybody in the audience is happy.) Now, simply, just with a bit biased rounding of  $G$ :

$$M = \frac{g \cdot R \cdot R}{G} \approx \frac{10 \cdot 6 \cdot 10^6 \cdot 6 \cdot 10^6}{6 \cdot 10^{-11}} \text{kg} = 6 \cdot 10^{24} \text{kg}$$

Finally, we have weighted the Earth!

## 5 Conical pendulum, weightlessness etc.

Further experiments can be described more briefly. First, we can move the hanging paperclip in circles to make conical pendulum – and to verify, that its period is the same as the period of normal pendulum of the same length.

While holding the end of a thread we can also jump from a chair or table and see that the paperclip falls with the same acceleration as our body. If you let your hand fall down freely, you may see nearly the same effect even without jumping. On the contrary, when making a show, I jumped from a table not with a paperclip but with an apple. And, of course, one may then speak about a principle of equivalence and to mumble something on general relativity...

## 6 Torsion pendulum

By pulling the straw through the hole in the paperclip you can create a small torsion pendulum, which can serve as torsion scales. (The paperclip, hanging on the thread, holds the straw in the middle. The straw should just fit into the paperclip.) The straw with the paperclip can turn

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around a vertical axis even when quite a small momentum of force is applied.

You can, for example, rub one end of a straw with a cloth and then put your finger close to this end of your torsion scales. You will see that your finger attracts the straw. If you rub another straw, the rubbed (i.e., charged) end of your scales will be repulsed from it.

And again, you can speak about Coulomb, about Cavendish experiment etc.

### 7 Forced oscillations

Using the paperclip hanging on a thread again as a normal pendulum you can demonstrate forced oscillations and resonance. Just move your hand back and forth in horizontal direction holding the thread – slowly at first, then faster and faster (i.e., with greater frequency). Of course, you cannot construct a resonance curve from such simple experiment. But you can mention not only the dependence of amplitude of oscillations on the frequency but also the behaviour of a phase. When the frequency is low, the motion of a paperclip is in phase with motion of your hand. Using a high frequency the paperclip moves just to the opposite side than your hand.

### 8 Angular momentum

The next experiment can be motivated by an astrophysical question: Why pulsars rotate so fast? Well, we know that they are formed by a collapse of stars and stars themselves rotate – but much slower. Why is it so?

A simple experiment may show the principle. Pull the thread through the straw (you can do this by sucking it in), hold the end of the thread and move the other end of a straw in small circles such that the paperclip will orbit around it. By pulling the thread you may decrease the radius of its orbit, and you will see that the orbital velocity of the paperclip increases!

And, even at a show, one can tell students about angular momentum and to explain why it is natural that pulsars rotate so rapidly after they are formed – and to arrive to an order of magnitude estimate, which corresponds with reality very well.

### 9 Friction

Hold the straw horizontally and turn the thread around it. By pulling the end of the thread you can lift the paperclip. You need not to pull much – the paperclip is very light. But if you turn the thread around the straw twice or three times you have to pull with much greater force. And if you turn it, say, eight times around, you probably will not be able to lift the paperclip at all. (Be careful not to damage the straw by pulling too strong.)

Of course, it is due to friction and you can now introduce Euler formula – or even to show students how to derive it as a solution of simple differential equations to satisfy those keen in mathematics... :-) Or you can use it as a motivation even to quantitative measurements.

### 10 Thread as a string

You can use your tool also for some experiments from acoustics. For example, the thread may act as a string. Hold one end of the thread in your teeth (pressing it tightly) and stretch the thread by pulling the paperclip away from you. Then you can pluck the thread – just like playing guitar. And you will hear the sound! Of course, it goes to your ears mainly through your bones...

If the string (the thread) is shorter or a tension in it is higher, the pitch of the tone is higher and vice versa. (You can show students wave equation at this occasion if you like, or just discuss the oscillations of a string by more simple means. :-)

One more thing you can hear and demonstrate is different colour of the sound. It depends on the point where you thum the thread. If you do it near the end the tone is “brighter” or “sharper”. It has more higher harmonics – another topic for discussion.

### 11 Diffraction – and the rest of it

Another experiment can bring us even to the area of wave optics. Hold the thread in front of you against some light surface (e.g. a wall). By moving the thread closer to your eye and farther you will find a place where you do not see one dark thin stripe (the thread itself) but rather two dark stripes with a light stripe between them...

Well, it seems to be enough experiments for a small show. (Ours lasted about three quarters of an hour.) What else to add?

The short description presented here could just indicate the ideas of experiments. One should add something to create the overall atmosphere. Assistants on stage presenting how to do the experiments. (Their tools included a “straw” about 1,5m long, a large “paperclip” from a thick wire etc.) The music at the beginning. A few surprising moments both at the beginning and at the end. And also a portion of humour – which perhaps can be perceived even in the text above.

Our “show” should have brought a joy of physics to its participants. It seems it did.

### Conclusions

The experiments described above are, of course, not the only ones we can do with a straw, a paperclip and a piece of thread. We tried to do a reasonable choice. But maybe you know some other experiments, more interesting, more surprising and more joyful. Or you would like to criticize or comment some of ours. If this is the case, please, let me know. There will be other occasions to spread the joy of physics ...

### References

(Ask people who were present at the “show” at GIREP 2004 for their references and impressions... :-)