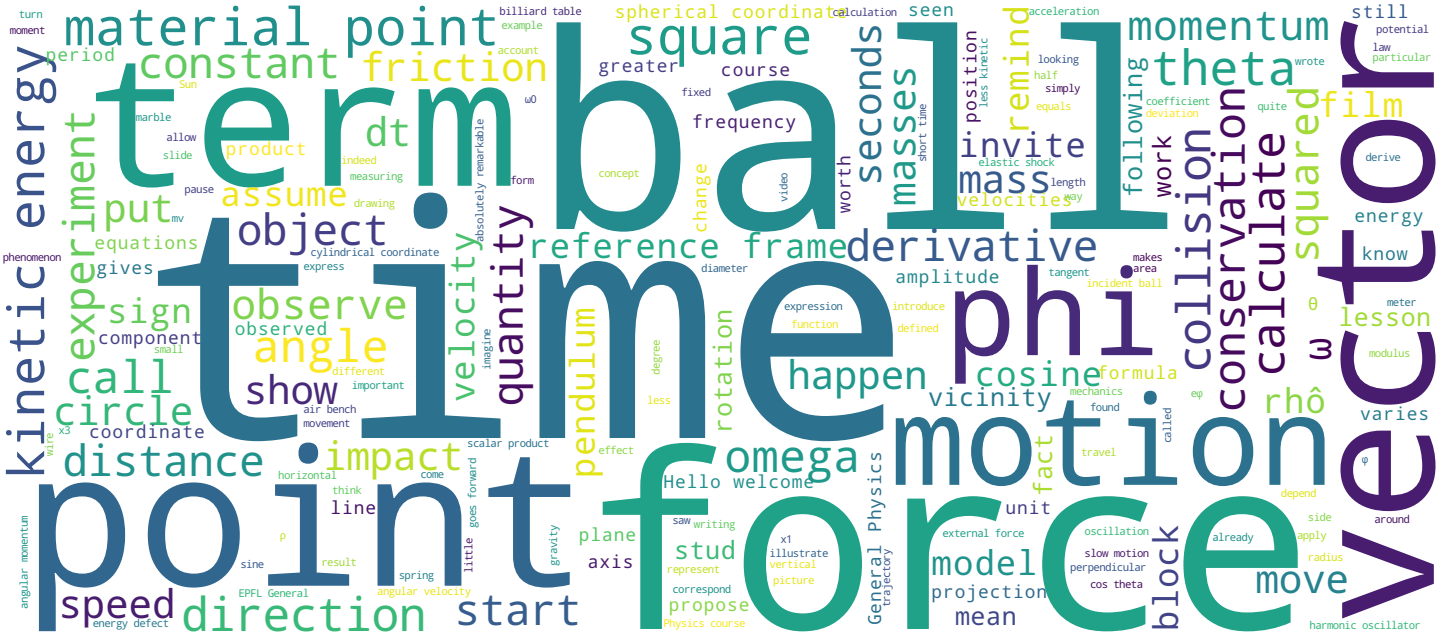
Expériences : collisions

Mécanique, cours 12.exp

Jean-Philippe Ansermet



Expériences : collisions

- Choc inélastique sur banc à air
- Choc élastique sur banc à air
- Choc élastique sur table à air
- Billard
- Chocs de billes aimantées

Mécanique | 2013 7

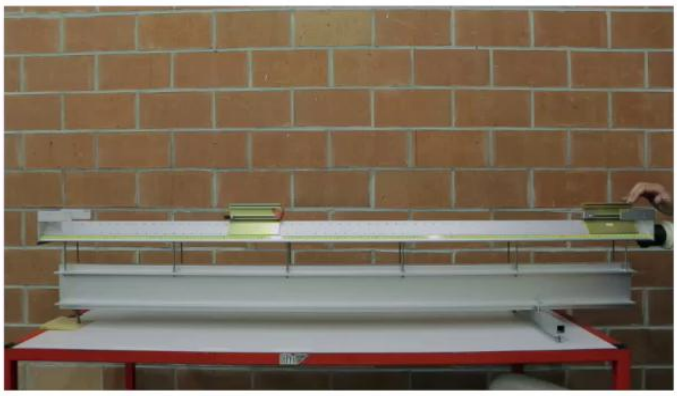
Hello, welcome to the EPFL General Physics course In this lesson we learned how to analyze collisions. Here, I will illustrate the concepts with some experiments. First, we will look at an inelastic shock, that is the meeting of two blocks on an air bench that stay together, then we will look at an elastic shock on the same air bench, then we will look a collision in two dimensions, and, speaking briefly about billiards, I will show you that when we have a billiard ball, we can have phenomena which are very different from what we can predict with the material point model. Finally we will look at collisions between balls one of which is magnetized, which will allow me to illustrate the concept of conservation of momentum over a very short time in the vicinity of a shock when there are external forces of finite size.

Notes

Summary

0m 03s

Choc inélastique sur banc à air



- La quantité de mouvement est conservée, pas l'énergie cinétique. De l'énergie est accumulée dans les déformations plastiques de la pâte à modeler.

I start with an inelastic collision. You have two studs, one is mounted with a nail that will stick into some orange plasticine on the other stud. Let's see what happens.

Notes

Summary

1m 06s

Here it is, after the collision the two studs are together.

Notes

Summary

1m 26s

Choc inélastique sur banc à air

Avant :

90 cm en 1.6 s : $0.56\,ms^{-1}$

Après:

45 cm en 1.7 s : $0.26\,ms^{-1}$

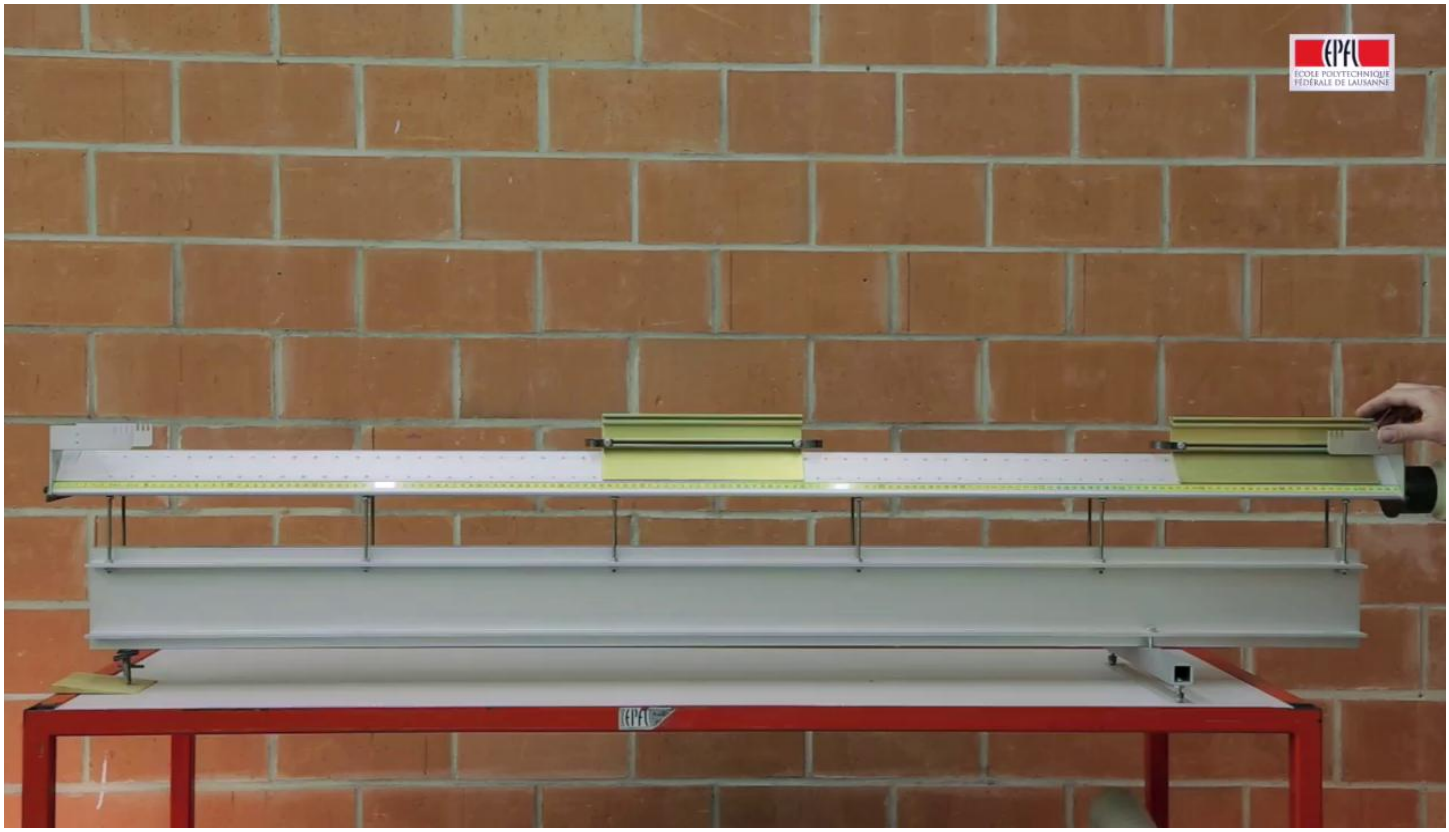
Remarque : longueur d'une brique, env. 30 cm

Then I had fun looking at the elapsed time for some distances measured in terms of brick length on the back wall of the auditorium, and I observed the following thing: before the collision the incident block has traveled 90 centimeters in about 1.6 seconds, this is very approximate, it corresponds to 0.56 meter per second. After, the two blocks together, travel about 45 centimeters in 1.7 seconds which corresponds to 0.26 meter per second, it's not quite a factor of 2 but considering the huge inaccuracies on the measurement of time I think it's still not bad.

Notes

Summary

1m 30s



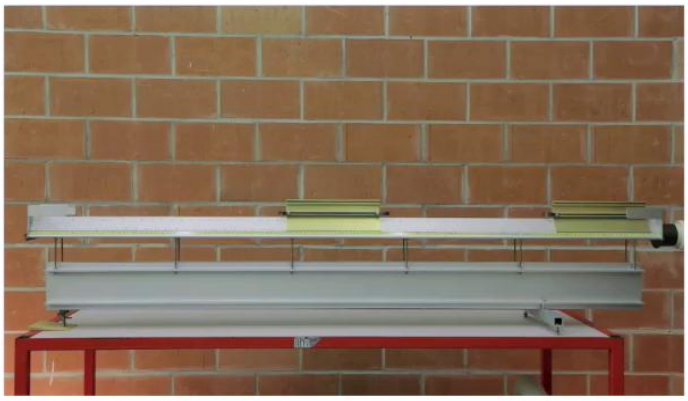
I now switch to an elastic collision. We have seen with all our equations that if we are in a rectilinear motion and that we have two equal masses, the one that is incident stops and the other one starts again. This is indeed what we observe. Look at this.

Notes

Summary

2m 23s

Choc élastique sur banc à air



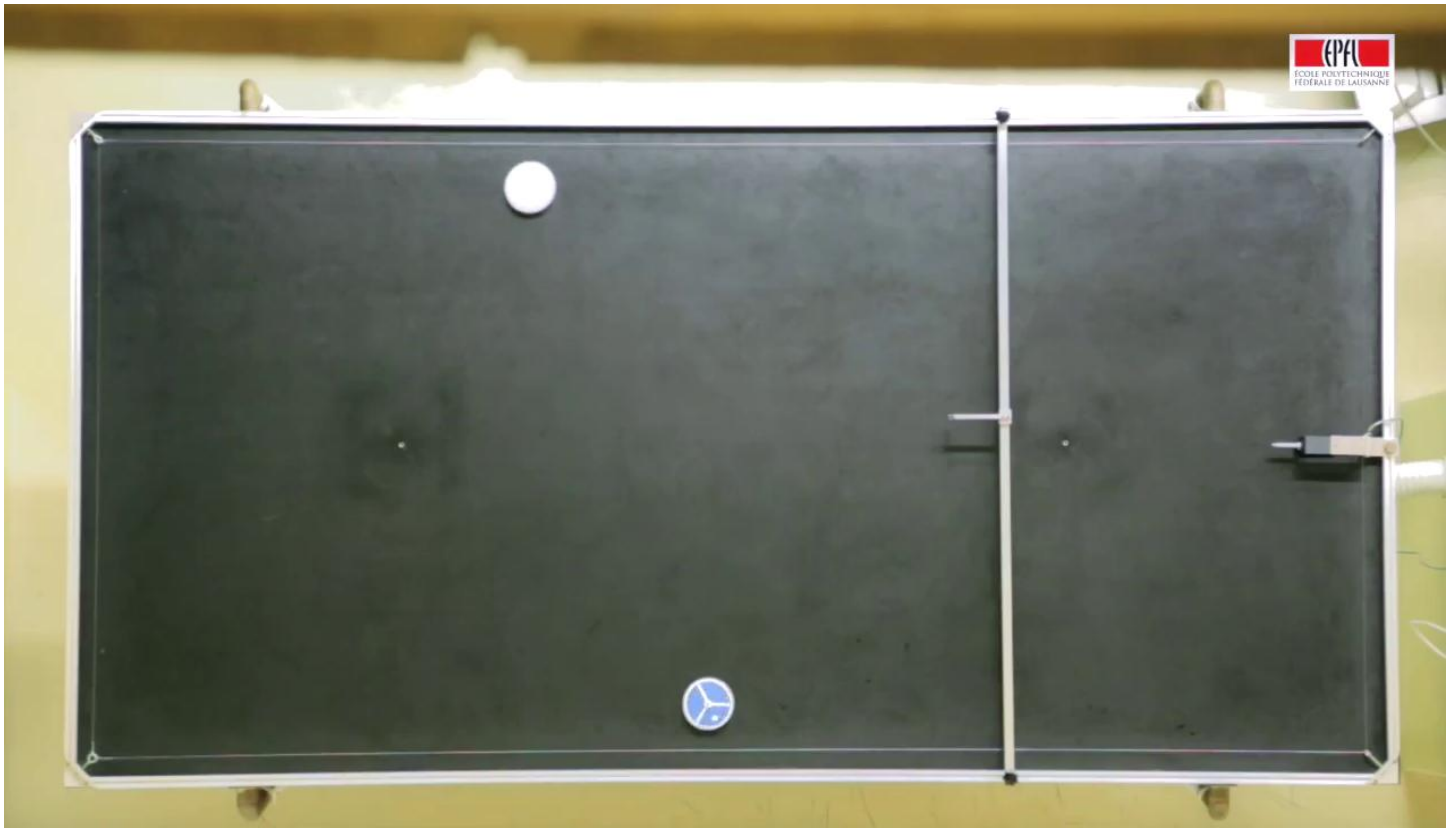
- Masses égales : le plot incident s'arrête, l'autre prend la vitesse du plot incident.

I would like to remind you that in this film, we are talking about an air bank, so there is practically no friction and you can see that the block that stops, stops perfectly. This is absolutely remarkable.

Notes

Summary

2m 52s



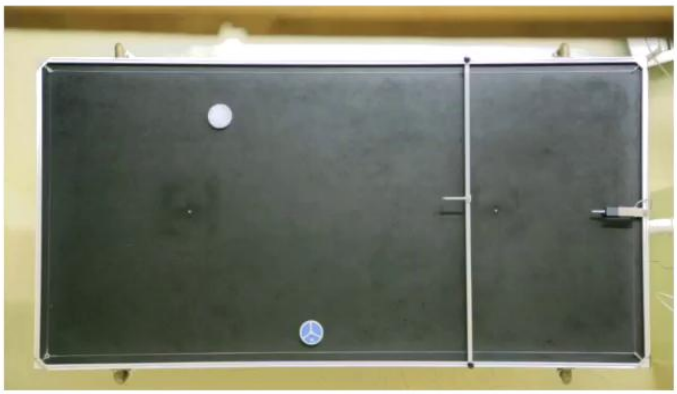
Now I'm going to move on to a two dimensional experiment. We are going to make a collision between two blocks on an air table and you will see what happens. We had foreseen, I remind you that theoretically we should have, the two blocks have equal masses, so we had foreseen theoretically for an elastic shock, that these two blocks move away from each other with orthogonal speeds. Let's see what happens.

Notes

Summary

3m 09s

Choc élastique sur table à air



- Selon l'analyse d'une collisions, si les masses sont égales, les deux plots s'éloigent à angle droit …

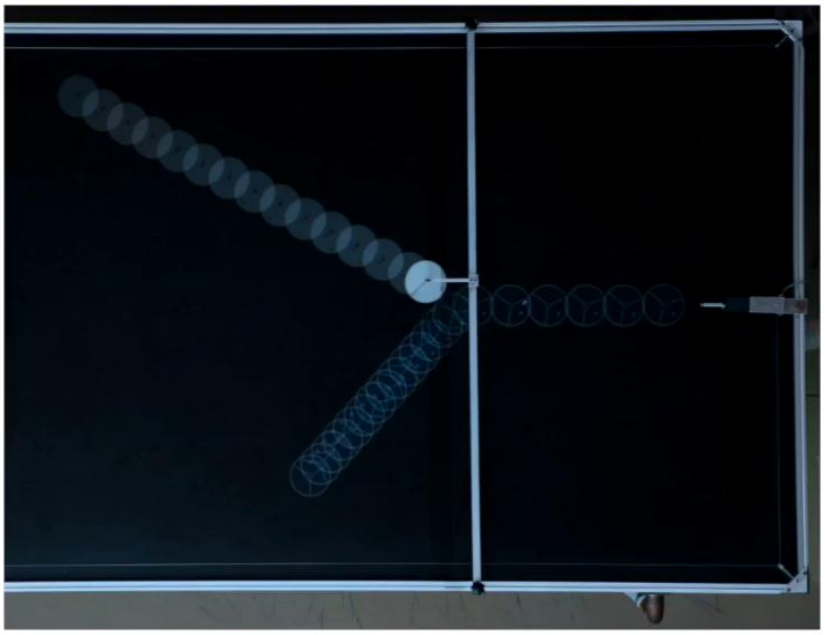
Looking at the film like this, I'm rather enthusiastic, I say to myself, here it is, it's magnificent, besides, for years, I did the experiment and in the audience without having a film, a more precise recording, I always said, here it is, it's 90 degrees. Now look, I have a little surprise in the making of this MOOC, we took a picture, this one.

Notes

Summary

3m 42s

Choc élastique sur table à air



And what you're looking at, a static image like this, it's not 90 degrees at all. So I invite you here to pause and try to account for this deviation from the theoretical prediction.

Notes

Summary

4m 05s

Choc élastique sur table à air

Pourquoi observe-t-on moins de 90 degrés ?

$$\boldsymbol{v}_{1i} = \boldsymbol{v}_{1f} + \boldsymbol{v}_{2f}$$

$$\boldsymbol{v}_{1i}^2 = \boldsymbol{v}_{1f}^2 + \boldsymbol{v}_{2f}^2 + 2\boldsymbol{v}_{1f} \cdot \boldsymbol{v}_{2f}$$

Perte d'énergie cinétique :

$$\boldsymbol{v}_{1i}^2 = \boldsymbol{v}_{1f}^2 + \boldsymbol{v}_{2f}^2 + Q$$

$$Q = 2\boldsymbol{v}_{1f} \cdot \boldsymbol{v}_{2f}$$

$$\cos\theta = \frac{Q}{2|\boldsymbol{v}_{1f}|\,|\boldsymbol{v}_{2f}|} \geq 0 \implies \theta \leq \frac{\pi}{2}$$

Mécanique | 2013 22

Personally I explain the phenomenon by assuming that the collision is not quite elastic. So here is how I do it. First I take the conservation of the quantity of motion, I remind you that we have equal masses, the quantity of motion, here P, is mv so the masses being equal, I still have the sum of the velocities but it's an expression of a very general principle, that of the conservation of the quantity of motion. I square this equation like this. Now to express the fact that the kinetic energy is not quite conserved, I will write the following: I no longer write as, basically, it would have to put half of m everywhere, I removed it to simplify the writings, and Q represents a kinetic energy defect. Okay, there is less kinetic energy after than before. So if I put this formula together with the square of the conservation of momentum, I get the following result: in other words, I can write that the cosine, because v1f scalar product with v2f that makes the products of the norms times the cosine of the angle so the cosine of the angle is Q out of 2 times the product of the speeds. Q is greater than zero because there is a kinetic energy defect, there is less kinetic energy after than before, so Q is greater than zero, so cos theta is greater than zero, that means theta is smaller than pi over 2. This is what I propose as an explanation for what we just observed.

Notes

Summary

4m 25s

Billard, au-delà du modèle du point matériel

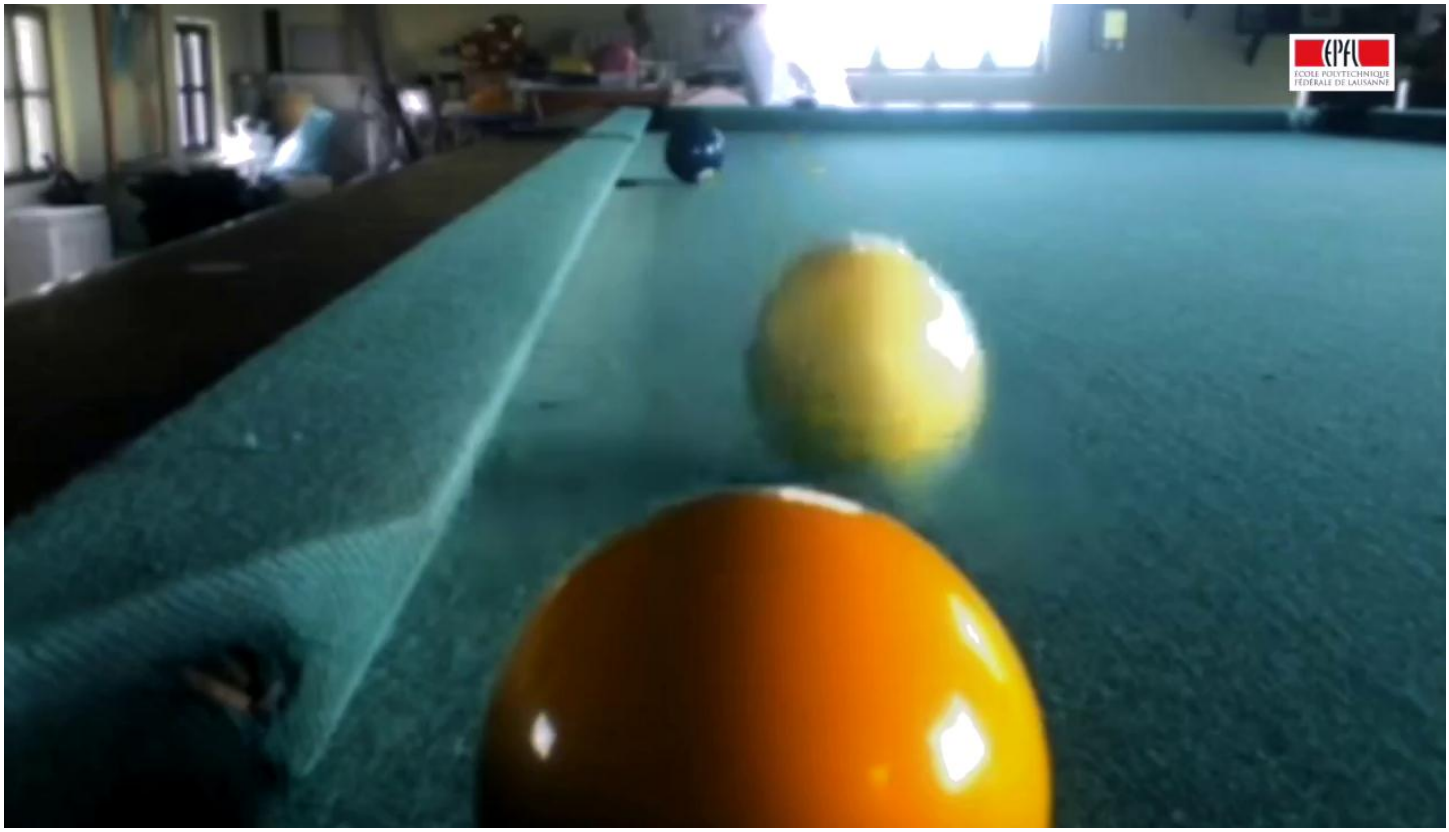
- Si l'objet tourne sur lui-même, des effets interviennent qui changent qualitativement la nature du mouvement.
- Voir par ex. : http://www.youtube.com/watch?v=mHXHCcQgD2I

Now I pass, - final caveat, we have treated these objects as if they were material points. We know that with a billiard table we can make a ball turn on itself and at that moment the model of the material point does not hold anymore. I found several examples of very strange trajectories on a billiard table, which can be obtained when the ball, again, turns on itself.

Notes

Summary

6m 15s



I'm showing you some snapshots from a film. So you have three balls lined up. The white one over there at the bottom is in line with the other two but the player has arranged for the white ball to go around the blue ball like this and come back down to collide with the orange ball. These are effects that only occur when you are beyond the material point.

Notes

Summary

6m 43s

Choc de billes aimantées

- Quel est le rôle du frottement dans ce phénomène ?

Mécanique | 2013 37

To finish, I invite you to look at an experiment which is conducted with magnetized balls.

Notes

Summary

7m 15s

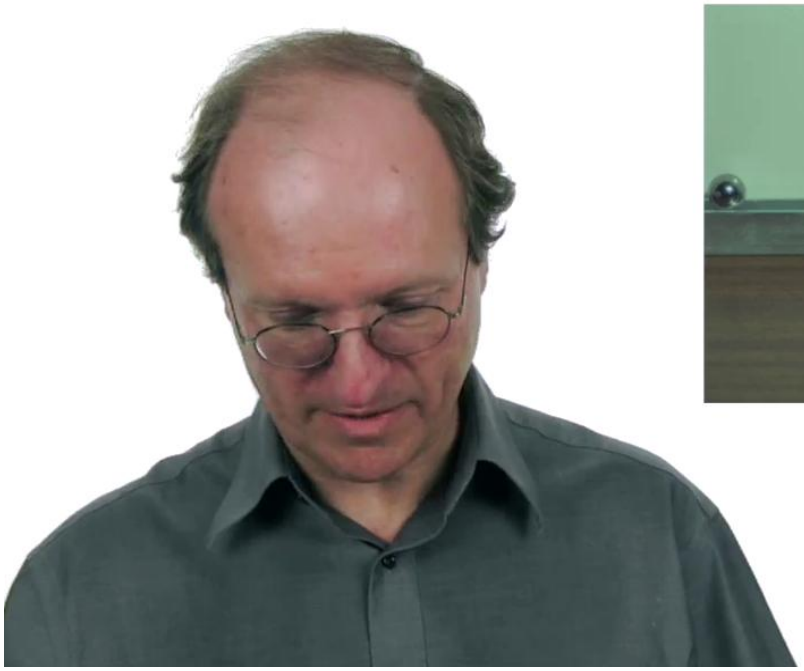
This is a very spectacular phenomenon and we can ask ourselves if the laws of mechanics can really account for what we have just seen or if there is something special that takes place because of magnetism and you will see that I can conduct an analysis perfectly well within the framework of Newtonian mechanics.

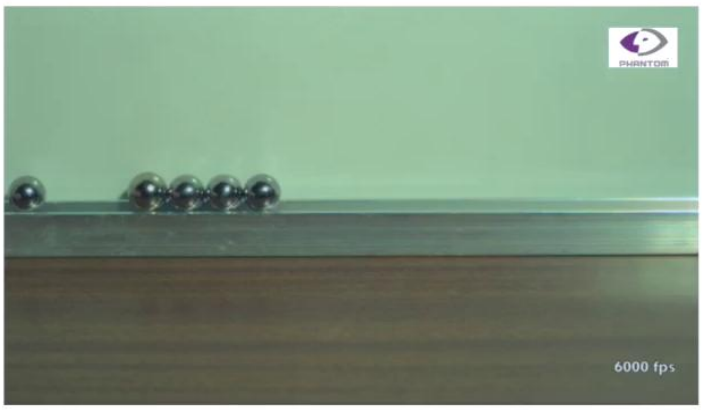
Notes

Summary

7m 41s

Choc de billes aimantées





- Avant :
  - 1 bille parcourt 1 diamètre de bille en 41.8– 39.2 secondes
- Après :
  - 1 bile parcourt 1 diamètre en 43.6 – 42.6 secondes
  - 4 billes parcourent 1 diamètre en 48.6-41-9 secondes

To begin with I would like to see this phenomenon in the vicinity of the collision. So on the next movie, we have a movie accelerated to 6000 frames per second, and we'll see what happens.

Notes

Summary

8m 05s

Obviously at the beginning things happen extremely slowly, considering the number of images per second we have, and suddenly, the incident ball is going to be as if caught by the 4 others and we will have the ejection of the first one. This is a slow motion movie, I remind you. You can see the retreat of the four balls. Here, I invite you to think about this problem, see if you can analyse it.

Notes

Summary

8m 22s

Choc de billes aimantées

Avant l'impact :
- Le frottement retient les 4 billes
- Le frottement est en avant
- La quantité de mouvement des 5 billes augmente

Analyse au voisinage de l'impact

Mécanique | 2013 45

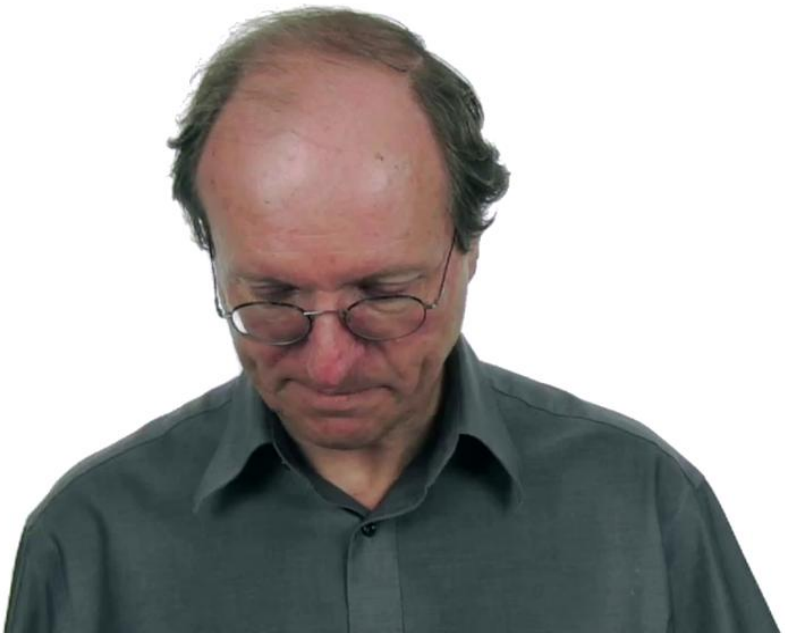
Personally I see the following things: long before the impact, we have four balls which are held back by friction on the rail and the incident ball arrives because of the magnetization, the ball is attracted to the first one so it gains kinetic energy but if you want, the quantity of motion of the four balls increases, I mean the five balls, the total of the five balls has a quantity of motion which increases thanks to the fact that there is friction. What happens then just at impact? I had proposed a model in which in the presence of finite forces, finite integrals, integrated over time around a time in the vicinity of the impact we have, if these external forces have finite values, then we can assume to have conservation of momentum over a very short time, and I claim that this is what happens here. Look. In the vicinity of the impact I'm going to measure the velocities, well the velocity of the ball just before the impact and the velocities of the two objects, the set of four balls on one side and the ball that goes forward, on the other.

Notes

Summary

9m 09s

Choc de billes aimantées



Avant l'impact :

- Le frottement retient les 4 billes
- Le frottement est en avant
- La quantité de mouvement des 5 billes augmente

Analyse au voisinage de l'impact

$D =$ diamètre de la bille

$m =$ masse de la bille

$$P_{init} = mD\frac{1}{2.6} \approx mD\,0.38$$

$$P_{final} = mD\left(\frac{1}{1.0} - \frac{4}{6.7}\right) \approx mD\,0.40$$

To do this I will call D the diameter of the ball, m the mass of a ball assuming that all the balls are identical, there may be small differences but that's not the important thing, I observe, I calculate, I observe the quantity of movement of the first ball, I looked at the speed of the ball over distance while it travels a distance equal to the diameter D and by carefully watching the video in slow motion, I saw that the ball took about 2.6 seconds to travel the distance of one diameter. So, the units are not explicit in there, because m and D are algebraic values and the numerical values, the 2.6 is seconds, so 0.38 is 1 over seconds, and you have P which is therefore the amount of motion, the mass times the velocity, shown like this where the only parameter I'm measuring is the travel time. Now I'm measuring the final momentum. I have two objects, I have an object that has four marbles hence the 4 that is here, and an object of one marble, I observed that this one marble alone moved the distance D, so one marble diameter, in one second, while the others took 6.7 seconds to move.

Notes

Summary

10m 33s

Choc de billes aimantées

Avant l'impact :
- Le frottement retient les 4 billes
- Le frottement est en avant
- La quantité de mouvement des 5 billes augmente

Analyse au voisinage de l'impact

$D =$ diamètre de la bille

$m =$ masse de la bille

$$P_{init} = mD\frac{1}{2.6} \approx mD\,0.38$$

$$P_{final} = mD\left(\frac{1}{1.0} - \frac{4}{6.7}\right) \approx mD\,0.40$$

Mécanique | 2013 48

And I deduce that the final quantity of movement, of course I have a minus sign because I have a ball that goes forward like the incident particle, the four others backwards and when I do this calculation, I find 0,4 against about 0,4 too. The precision, it is absolutely remarkable and therefore I trust once again that the mechanics works in this magnetic case too.

Notes

Summary

12m 13s