

Practical 1 – Topic 2

In this experiment the students are asked to design and carry out an experiment to investigate a factor that affects the bounce of a ball. The type of ball is left up to the student. The students are free to use whatever equipment is available in the lab.

Here is one possible approach to this investigation by a student.

Investigating a factor affecting the bounce of a ball, Student report

Criteria assessed

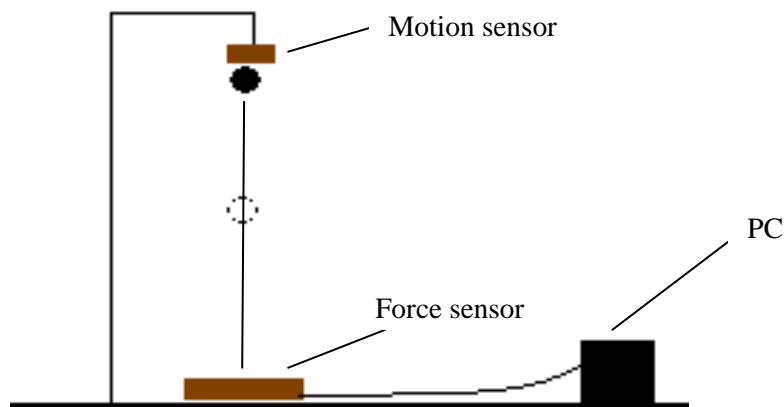
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Investigating a bouncing ball

The aim of this experiment is to investigate how the impulse on a bouncing ball during its first collision with the floor depends on the air pressure inside the ball. In order to do this, the following apparatus is required:

- a bouncing ball whose pressure is changed by a pump
- a pressure gauge
- a force sensor connected to a PC with the program *Logger Pro* installed
- a pump.

However, a motion sensor was also available and so it was used in order to better understand the motion of the ball. Although we are only interested in the results provided by the force sensor, the motion sensor gives us information that can be analysed in the evaluation of the experiment. The setup of the apparatus is shown in the following sketch.

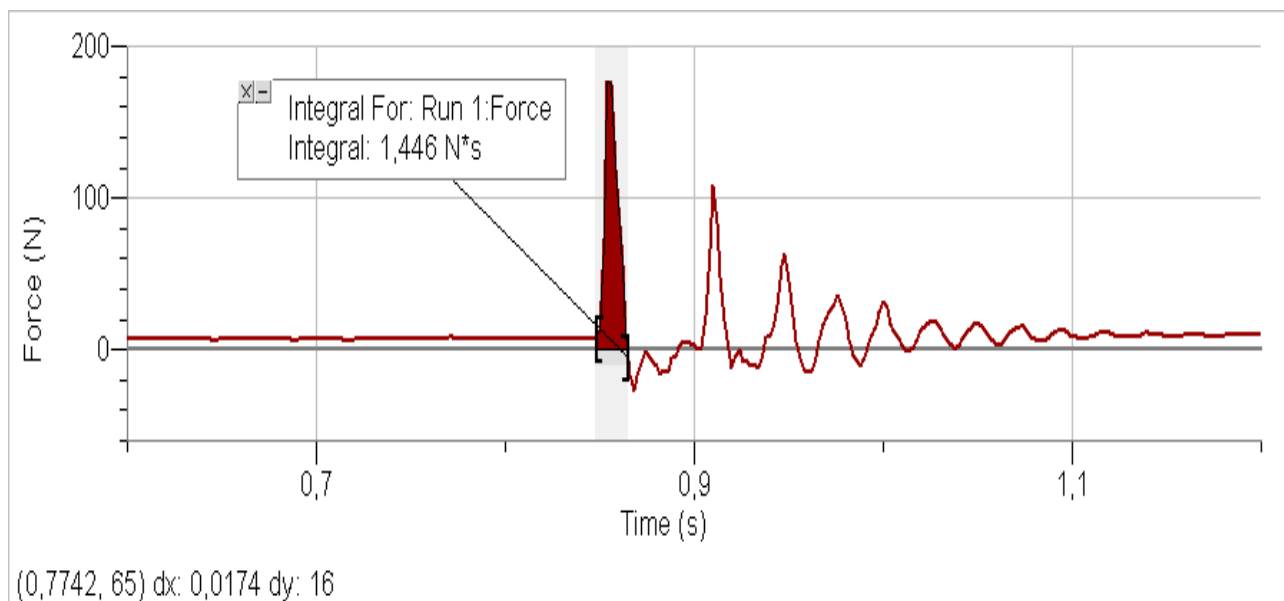


The same ball was used in all the measurements and was small in size. The height was also constant throughout the measurements.

The ball was filled with air using the pump and then the pressure was measured with the pressure gauge. Five different impulse measurements were taken at this pressure by releasing the ball and using the sensors. The pressure was then re-measured to make sure that it had not changed.

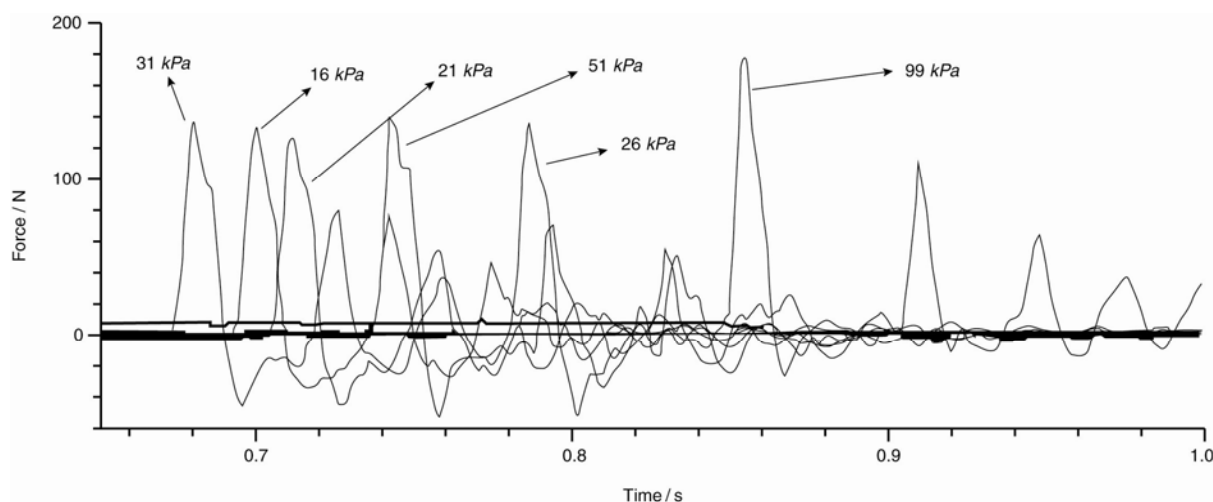
Some of the air was let out from inside the ball, in order to reduce the pressure. The new pressure was measured and five impulse measurements were taken. In total we took measurements for six different pressures.

In order to calculate the impulse on the ball, we used the *Logger Pro* program. The force sensor produced a graph of 'Force' against 'Time', similar to the following one, for each different measurement. The following graph corresponds to a pressure of 91 kPa. The impulse during the first bounce of the ball was measured as the area under the graph for the time interval of the first bounce.



Clearly, however, the above measurement has a systematic error since the force sensor is recording a positive value of force when nothing is in contact with it. Therefore, we have to subtract the area of a parallelogram, which has Δt , the time of contact with the force sensor, as one side and the zero reading as the other. The area subtracted is simply $A = N_0 \Delta t$ and so the impulse value is $I = \text{integral} - N_0 \Delta t$. Note that this systematic error did not occur in every measurement.

By doing the above process for each different measurement, we were able to obtain values of impulse for each different pressure. The following graph contains measurements for each different pressure value.



Clearly, at lower pressures the force felt by the ball does not change significantly. However, from the above graph one cannot distinguish the effect of the systematic error, which is present in some of the measurements, on the force value.

Collected data

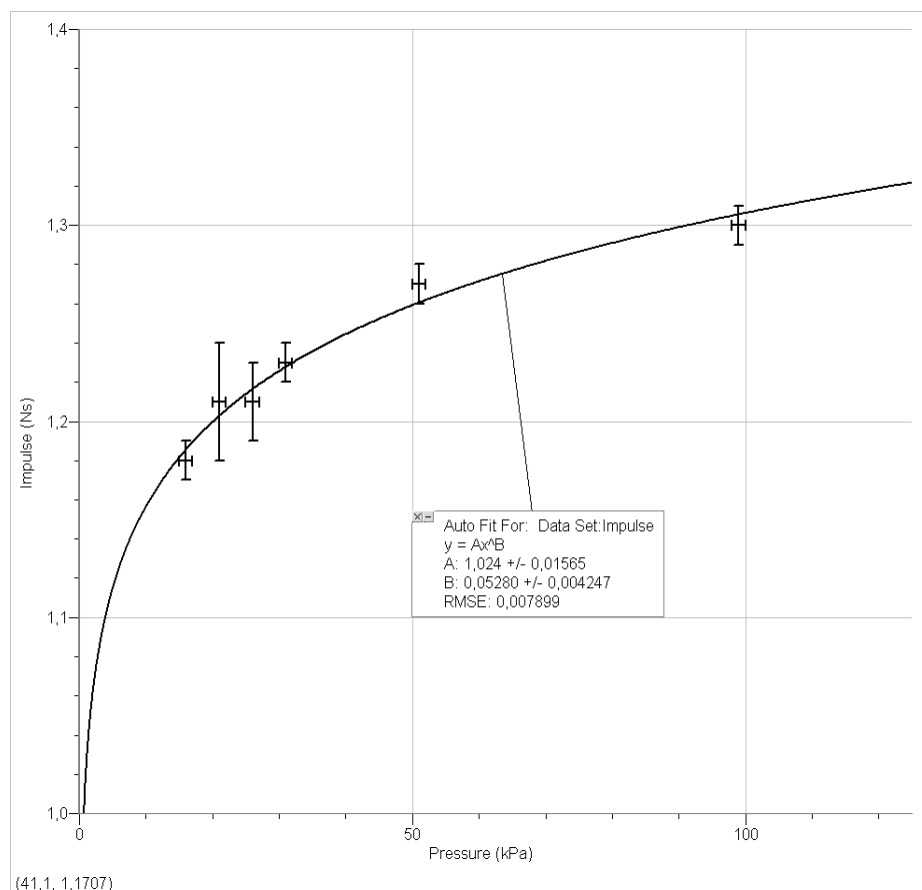
The following table contains five different values for the impulse felt by a bouncing ball on its first collision with the floor for different values of pressure inside the ball. These values of impulse were calculated using the previously explained method. Pressure values, as measured by the pressure gauge, are also shown.

Pressure (kPa)	99.0	51.0	31.0	26.0	21.0	16.0
1st impulse measurement (N s)	1.294	1.284	1.227	1.226	1.208	1.191
2nd impulse measurement (N s)	1.297	1.261	1.247	1.201	1.234	1.179
3rd impulse measurement (N s)	1.304	1.277	1.230	1.203	1.232	1.183
4th impulse measurement (N s)	1.283	1.254	1.228	1.185	1.183	1.194
5th impulse measurement (N s)	1.316	1.269	1.225	1.236	1.180	1.159

The following table contains an average value of the impulse for the different values of pressure. The absolute uncertainty of each impulse value ΔI is found by calculating the standard deviation of the five different impulse values. The absolute uncertainty of the pressure value is assigned to 1 kPa, since there is an important rounding error related to the value displayed by the pressure gauge.

Pressure (kPa)	99 ± 1	51 ± 1	31 ± 1	26 ± 1	21 ± 1	16 ± 1
Average impulse (N s)	1.30	1.27	1.23	1.21	1.21	1.18
ΔI (\pm)	0.01	0.01	0.01	0.02	0.03	0.01

The above data can now be plotted on a graph of 'Impulse' against 'Pressure'. The appropriate uncertainties are also shown. A power fit seems to be the best attempt of curve fitting. The fit is successful since the curve plotted passes through the uncertainty bars of all values. The value of the root mean square error (RMSE) is low, which shows that the curve fitting is successful.



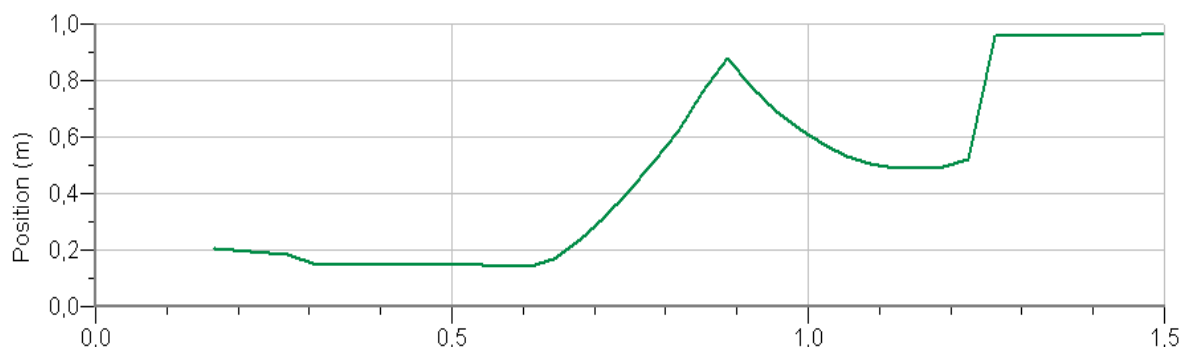
Conclusion and evaluation

The measurements we made allowed us to plot a graph of ‘Impulse’ against ‘Pressure’ in order to investigate how the impulse on a bouncing ball during its first collision with the floor depends on the air pressure inside the ball. The graph was successful since the curve passed through the error bars of all points and the root mean square error was significantly low. The power fit was successful; however, the fact that the relation between impulse and pressure turned out roughly to be $I = cP^{1/20}$ kPa, where the pressure is measured in kPa, implies that the physics related to our investigation is quite complicated.

There are many different factors that affected our experiment.

First of all, when measuring the pressure inside the ball, some of the air may have escaped while inserting and removing the pressure gauge, which means that the pressure inside the ball might have been different from the value measured. In an effort to control this effect we measured the pressure of the ball both before and after taking the measurements; if a significant change was observed we restarted the process.

The height from which the ball was released was assumed constant, although this was not always the case. An effort was made to ensure that the ball was released exactly below the motion sensor. However, as the following ‘Position’ against ‘Time’ graph, shows, the ball’s distance from the motion sensor seems to change due to the instability of the hand holding it. This graph was produced with the help of the motion sensor. A systematic error is also easily visible on the graph. However, the effect of such differences is negligible since the height is much larger than the small differences in the distance from the motion sensor.



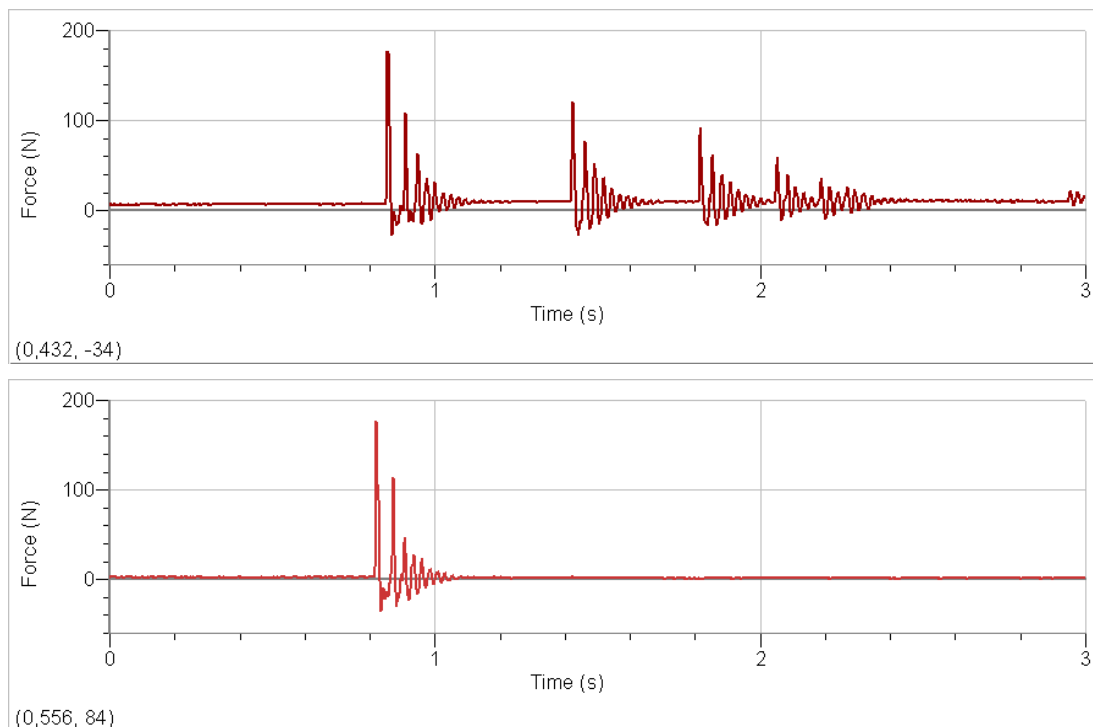
Our experimental setup also allowed us to obtain other interesting information. For instance, the graph above allows us to measure the distance between the motion sensor and the force sensor – after about 1.3 s no object is between them. Even more interestingly, we can measure the diameter of the ball since it is equal to the difference in the distance from the motion sensor measured at the time of the collision (at the peak of the below graph, ≈ 0.9 s) and once no object is between the two sensors (after 1.3 s).

Another important factor is that the surface of the ball was not uniform, therefore the collisions cannot be considered identical. Additionally, certain points on the surface of the ball are sharper than others, especially where the different parts of the ball are stitched together. A sharper edge affects both the time of contact with the floor and the force exerted on the ball.

Additionally, as air is pumped into the ball, more molecules of air are now concentrated inside the ball, increasing its mass. Nevertheless, this effect is also negligible since the mass difference is very small in comparison to the mass of the ball. Furthermore, air resistance is not negligible. Its effect would not interest us if it were the same for each different measurement; however, the value of the resistive force is not constant for each measurement, which affects the speeds with which the ball reaches the force sensor.

One can always evaluate the effectiveness of the sensors. The fact that the force sensor seems to produce different systematic errors from measurement to measurement shows that it is not completely reliable. Differences in room temperature may affect the way the sensors function. Additionally, the small size of the ball makes the motion sensor quite inaccurate since it is unable to detect the ball the

further away it moves. Since the surface of the ball is not planar, the motion sensor receives waves from different parts of the ball, which are at different distances from it. One must also note that the ball was not always released vertical to the force sensor, which certainly affects the measurements. This can be easily seen from the two following graphs. In the first graph, the ball falls almost vertically and so many bounces are shown. In the second graph the ball seems to rebound from the force sensor at an angle, so that no more bounces are shown.



A very important effect, which is also observable in the above graphs, concerns the forces exerted on and by the force sensor. As the ball collided with the force sensor, it exerted a force on it. In turn the force sensor exerted this force on the floor and by Newton's third law the floor exerted an equal force in the opposite direction on the force sensor. This force accelerated the force sensor upwards, which certainly affected the force measurements.

Finally, one must comment that although five measurements for each pressure and in total six different pressure values give adequate data, processing them created undesired errors. When using the *Logger Pro* to calculate the area under the graph, we had to specify the boundaries between which the area was to be measured, in order to only consider Δt , the time of contact with the force sensor. These boundaries did not always correspond to the values desired, which are the first instant of contact of the ball with the force sensor and the instant the ball loses contact with the force sensor. The fact that we had to add or subtract the systematic error, which was not easily read, made this effect even more important.