PHYSICS

Is the loudness of a ball that you drop a measure of the amount of energy you put in to lift it?

Asked 2 years, 5 months ago Modified 2 years, 5 months ago Viewed 453 times

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When you lift a heavy object off the floor and raise it then you've exerted an amount of work/energy on that body. When you release the heavy object gravity exerts the same work/energy. But when you lift the ball nothing dramatic happens. You lift it and that's it. When you drop the ball there is a loud bang when the ball hits the floor. What accounts for this difference? It seems that it must be that there is an equivalent amount of energy in your body as in the sound (assuming that the floor doesn't change so that most of the energy goes into sound). Is this accurate reasoning? Can you do sound calorimetry?

newtonian-mechanics energy-conservation acoustics collision projectile

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edited Mar 10, 2021 at 9:01
Qmechanic ♦
192k 43 506 2172

asked Mar 10, 2021 at 4:51
user288901

3 Answers

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Bottom Line Up Front

This is a complicated problem, but with some simplifying assumptions and some (hopefully) reasonable guesses, I think the sound amplitude will increase about 6 dB for a doubling of drop height, and the sound energy is (very) roughly proportional to the square of the kinetic energy of the ball dropping.

Discussion

Sound is a mechanical wave through a medium, which in this case is air. There are two common sources of sound energy: a directional forcing of the air, or an omni-directional expansion/compression of the air. While I am have not studied this particular sound problem in detail, I would expect the dominant sound source to be the compressive type as the ball compresses the air between it and the ground. Other sound sources include the elastic response of the ball (maybe dominated by the directional forcing?) and the sound of the ball falling (comes from the turbulent wake and is actually a different source type than the two I described above). Let us consider a perfectly inelastic ball (to ignore the elastic response) that is shaped like a pancake (to get rid of some of the hairy geometry that complicates our understanding).

As the ball (OK, it is really a pancake) falls and hits the ground, the air underneath it needs to get out of the way. If the impact happens slowly enough [e.g., you gently slide the pancake onto the surface (I am imagining making a classic American breakfast with a spatula, at this point)], the air motion can be laminar and very little compression will happen. That compression that does occur and generates sound waves will have a very low frequency which, for complicated reasons I won't go into here, won't propagate and won't be audible. As the pancake falls faster the air needs to move faster and will start to compress more, leading to audible sound generation. I am purely guessing here (again, I have not studied this problem in depth), but my intuition from fluid mechanics suggests that the linear rate of compression is proportional to the square of the falling velocity after some critical sound-generating velocity, or

$$p_{\text{out}} = A(v - v_0)^2 \equiv A\Delta v^2,$$

where p_{out} is the pressure generated at the edge of the pancake, A is some constant, v is the pancake fall velocity, v_0 is the critical pancake velocity, and $\Delta v = v - v_0$ is the velocity above the critical velocity. This expression would only be valid for $v \geq v_0$.

Assuming that my guess in the previous paragraph is correct, we can now talk about the loudness. Human perception of sound is actually very complicated (you can see [the Wikipedia article] for a taste), but we will use the decibel level as a useful and simple surrogate. The level of a sound wave in air is given by

$$L = 20\log_{10}(p/p_{\text{ref}}),$$

where p is the pressure amplitude and p_{ref} is a reference pressure of 20~μPa. Substituting the above expression then yields

$$L = 20\log_{10}(A/p_{\text{ref}}) + 40\log_{10}(\Delta v).$$

Ignoring the effects of air resistance on the fall velocity, we can estimate v from the interchange of kinetic and potential energy, such that $v \approx \sqrt{2gh}$, where g is the gravitational acceleration and h is the height of the drop. For drops sufficiently high that $v \gg v_0$, we can then approximate

$$L \approx C + 20\log_{10}(2gh),$$

where C is some constant. Thus, doubling the height would increase the level by $20\log_{10}(2) \approx 6$ dB.

Finally, some comments on sound energy. For a purely propagating plane wave (and for spherical waves sufficiently far from the origin) the acoustic energy is proportional to the square of the pressure. In our case here we find that

$$p^2 = A^2\Delta v^4 \approx A^2 v^4 \propto E_k^2,$$

where E_k is the kinetic energy of the pancake. Thus, the sound energy is proportional to the square of the kinetic energy.

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answered Mar 10, 2021 at 11:16

Michael M

1,675 8 13

-1

The loudness is more tied to the *loss* of energy. When the ball hits the ground, especially if it's a relatively inelastic type of ball or badly pumped, or if the floor is inelastic, mechanical energy is released, some of it as sound.

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answered Mar 10, 2021 at 6:05

Kristoffer Sjöö

572 2 7

-1

> You lift it and that's it. When you drop the ball there is a loud bang when the ball hits the floor. What accounts for this difference?

The difference lies in power i.e. rate at which energy is released or absorbed . When the ball is lifted energy changes occur gradually while the collision occurs within a second .

Think how of we don't hear any sound when air leaks from tires over days but when tires blast they make a ...well a blast sound, the energy changes are almost same in both cases but the sounds completely different . I don't have clear knowledge of how sound generation occurs .

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answered Mar 10, 2021 at 6:11

Protein

695 4 16