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Examining energy storage and work done by elastic jumping poppers

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This experiment investigated energy storage and work done in elastic jumping poppers as nonlinear elastic systems. The maximum gravitational potential energy during launch was determined from video analysis, while force–displacement measurements obtained during compression were numerically integrated to calculate the work done on each popper. The force–displacement data revealed nonlinear elastic behavior characterized by snap-through instability. The measured launch energies were lower than the work calculated from compression measurements, indicating that although the poppers clearly stored and released elastic energy, the two methods did not produce close quantitative agreement under the conditions of this experiment.

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I. INTRODUCTION

Elastic materials store energy when deformed and release that energy when allowed to return toward an equilibrium configuration [1–5]. While many elastic systems are well approximated by linear force–displacement relationships, real materials and structures often exhibit nonlinear behavior. One important form of nonlinearity is snap-through instability, in which increasing deformation leads to a maximum restoring force followed by a sudden decrease as the system rapidly transitions into a new geometric configuration. This behavior is characteristic of thin shells and domed elastic structures, including the poppers used in this experiment. During snap-through, elastic potential energy is released abruptly, and the structure's internal resistance drops even as displacement increases, producing rapid motion that cannot be accurately described using simple linear elastic models [6, 7].

The concepts of energy conservation and work provide a more general framework for analyzing such systems [1–3]. Mechanical energy exists in multiple forms, including kinetic energy $\mathrm{KE} = \frac{1}{2}mv^2$ and gravitational potential energy, $\mathrm{GPE} = mgh$. In ideal systems, the total mechanical energy remains constant. When an elastic object is compressed, mechanical work is done on the system and stored as elastic potential energy, which may later be converted into kinetic and gravitational energy. For 1D systems with variable force, the work done is given by the integral [1–3]:

$$W = \int F(x)dx \tag{1}$$

According to the work-energy theorem, the net work done on a system is approximately equal to the change in its mechanical energy, allowing independent experimental measurements of work and mechanical energy to be directly compared [1–3, 8].

The purpose of this experiment was to test the general concept of energy conservation, and to analyze rubber jumping poppers as nonlinear elastic systems by (1) measuring maximum gravitational potential energy during launch using video analysis, and (2) determining the work done during compression from force-displacement data. These measurements were used to test whether the energy gained during launch was comparable to the work stored during compression in the presence of snap-through instability.

Based on energy conservation, we hypothesize that the total mechanical work (W) done on the popper during compression should be equal to both the initial kinetic energy (KE_0) on launch and the maximum gravitational potential energy (GPE_f) at the highest point of its flight. Alternatively, if loss mechanisms, such as nonlinear material properties, effects associated with snap-through instability, friction, and air drag, are large, then the kinetic and gravitational potential energies will be less than the mechanical work done:

$$H_0 : W = \mathrm{KE}_0 = \mathrm{GPE}_f \tag{2}$$
$$H_1 : W > \mathrm{KE}_0 > \mathrm{GPE}_f \tag{3}$$

II. METHODS AND MATERIALS

This experiment utilized three toy poppers of different masses ("Jumping Gens"; Liberty Imports; Allentown, PA). These poppers included a heart-eyes emoji popper ($m = 0.0053\,\mathrm{kg}$), a crying emoji popper ($m = 0.0055\,\mathrm{kg}$), and a shocked emoji popper ($m = 0.0057\,\mathrm{kg}$).

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A. Launch kinematics and GPE

Motion during the launches was recorded using an iPhone 16 Pro Max (Apple; Cupertino, CA) positioned perpendicular at a fixed distance of 2.00 m from the launch point, recording at 60 frame/s with a resolution of 1080p. A meterstick was placed in frame for scale.

Each popper was placed on a flat surface (the floor) and launched using a manual downward push, intended to be as consistent as possible across all trials. While the magnitude of the applied force could not be directly controlled or measured, care was taken to apply a similar force during each launch. Three trials were chosen for each popper to balance repeatability with time constraints, and averaging was used to reduce variability from manual launching. A failed launch was defined as any trial in which the popper tipped, slid laterally, failed to fully invert, or did not produce a clear upward trajectory. Repeated trials were conducted to reduce the variability caused primarily by the manual push.

Video data were analyzed using Tracker [9, 10] to determine the maximum height (h) reached in each trial. Digitization proceeded similar to [11–16]. The measured heights were used to calculate the gravitational potential energy reached by each popper at the top of its motion according to:

$$\mathrm{GPE}_f = mgh, \tag{4}$$

where m is mass, and $g = 9.81\,\mathrm{m\,s^{-2}}$.

Variability in launch conditions was reflected in the spread of measured energies and accounted for in our discussion. Subsequent graphs and statistical analyses were performed in Python using the `numpy` and `matplotlib` libraries [17–19].

B. Mechanical work during compression of poppers

To determine the work done in compressing each popper, force-displacement measurements were obtained using a standard laboratory scissor jack and a digital scale (TOP2KG; Smart Weigh; Jiangsu, China). Each popper was placed between the scissor jack and the scale and compressed in increments of 0.005 m. The force exerted by the popper (as read on the digital scale, converted according to $F = mg$) was recorded at each displacement. Compression continued up until and slightly beyond snap-through instability occurred, indicated by a sudden decrease in measured force as the popper physically inverted.

Force-displacement data were collected for the three respective poppers to provide reasonable average data. Work was calculated by numerically integrating the force-displacement data using the trapezoidal rule [17, 18, 20], which estimates the area under the force-displacement curve without assuming linear elasticity.

Data and analyses are available at `https://github.com/devangel77b/427bdemairo-lab3`.

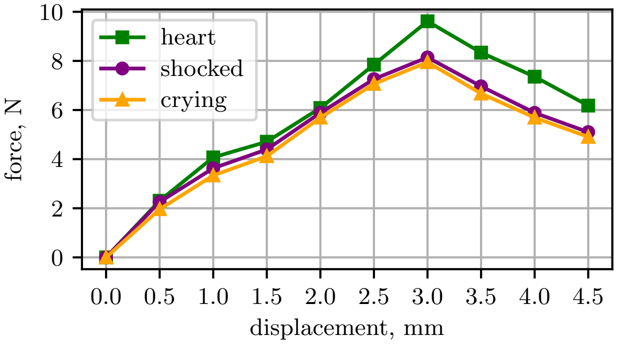

FIG. 1. Compressional displacement vs. elastic force for all three poppers.

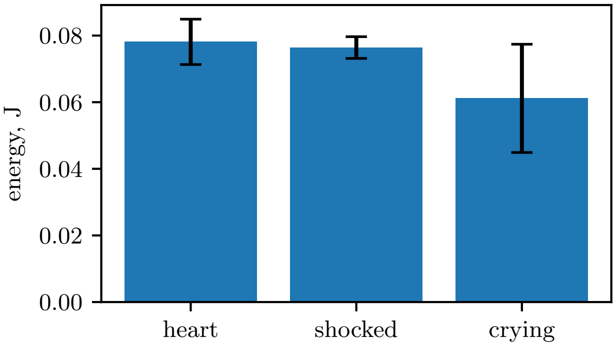

FIG. 2. Average maximum gravitational potential energy for all three poppers (J).

III. RESULTS

The graph shown in Fig. 1 shows a roughly linear relationship between the elastic force of all of the poppers and the compressional displacement up until it reaches the snap-through instability point, which can be seen at the peak of the graph, after which the relationship trends downwards due to the conical nature of the popper's spring. From the experimental results, we can see that the force of the heart-face popper remains consistently higher than the shocked-face popper, indicating that the heart-face popper exhibited greater effective stiffness over the initial compression range. The same trend applies to the shocked-face popper compared to the crying-face popper. From this, we can conclude that the heart-face popper has the highest elastic stiffness of all three poppers. Furthermore, we can conclude that the snap-through instability point occurs at a compression of approximately 0.03 m, as indicated in Fig. 1.

Video analysis was used to determine the maximum height reached by each popper in each trial. Using these measured heights, the poppers' maximum gravitational

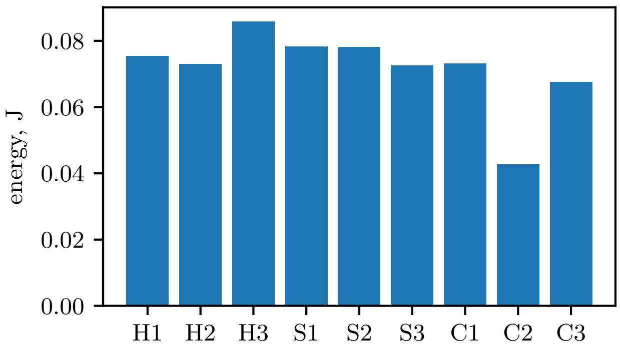

FIG. 3. Per-trial maximum gravitational potential energy for all three poppers (J).

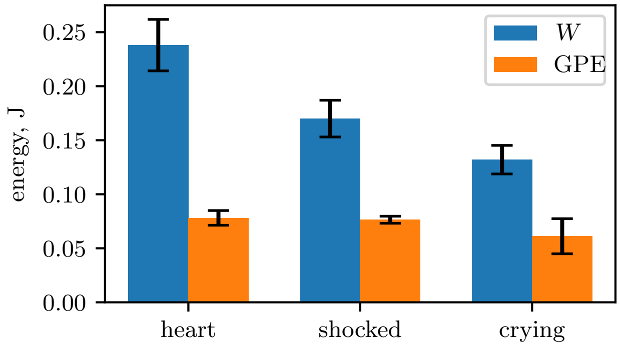

FIG. 4. Comparison of work done during compression and maximum gravitational potential energy gained during launch.

potential energy was calculated, resulting in average values of 0.0781 J for the heart-eyes popper, 0.0764 J for the shocked popper, and 0.0611 J for the crying popper, as shown in Figs. 2 and 3. Individual trials showed variation due primarily to differences in manual launch force. The heart-eyes popper achieved a mean peak GPE of 0.0781 ± 0.0068 J, the shocked popper 0.0764 ± 0.0033 J, and the crying popper 0.0611 ± 0.0162 J. A one-way ANOVA revealed no statistically significant difference in launch GPE across the three popper designs ($F(2,6) = 2.45$, $p = 0.167$). The observed ranking (heart-eyes > shocked > crying) is therefore descriptive rather than statistically confirmed, a limitation attributable primarily to the small sample size of three trials per popper.

Work calculated from force-displacement integration was greater than the maximum gravitational potential energy measured from video analysis for all three poppers, as shown in Fig. 4. This indicates that the two methods did not produce close quantitative agreement under the conditions of this experiment.

IV. DISCUSSION

A. Energy is conserved

The results of this experiment demonstrate that elastic jumping poppers store mechanical energy during compression and release this energy through snap-through instability during launch. Video analysis showed that each popper gained measurable gravitational potential energy during flight, while force–displacement measurements revealed nonlinear elastic behavior that cannot be accurately modeled using Hooke's Law ($F = kx$, where force is proportional to displacement in linear elastic systems) alone. Although variability was introduced by manually applied launch forces and measurement uncertainty, repeated trials and averaging produced consistent trends across all poppers.

However, the work values obtained from force–displacement integration were significantly larger than the maximum gravitational potential energy values measured from launch height (Fig. 4). This lack of close agreement suggests either substantial energy losses, overestimation of compression work from friction between the popper and scissor-jack platform, or additional uncertainty in the experimental methods. Therefore, while the experiment clearly demonstrated elastic energy storage and release, it did not support the null hypothesis that work done during compression is approximately equal to the mechanical energy gained during launch. The paired t-test ($t(2) = 4.05$, $p = 0.056$) approached but did not reach conventional significance, given the small sample; however, the mean recovery of only 41.3% of compression work as launch GPE represents a practically large discrepancy unlikely to result from measurement uncertainty alone. The ANOVA across poppers ($F(2,6) = 2.45$, $p = 0.167$) confirmed that differences in launch GPE among the three designs were not statistically distinguishable at this sample size, so the ranking of heart-eyes > shocked > crying should be treated as descriptive.

Variability in measured energy values is primarily due to the use of a manual launch force, which could not be directly controlled or measured in a consistent manner. However, repeated trials and averaging helped reduce this variability and revealed consistent overall trends. The experiment successfully demonstrated that poppers can be analyzed as elastic systems using energy methods, while also highlighting the limitations of assuming close quantitative agreement between compression work and measured launch energy in a real nonlinear system. These results indicate that poppers can be effectively modeled using energy concepts, while also emphasizing the effects of experimental uncertainty and non-ideal energy transfer.

B. Energy loss during launch process is significant

If the system were ideal, max GPE should equal compression work. The observed mean loss of 58.6% can be partially attributed to known physical mechanisms. The coefficient of restitution for natural and silicone rubber falls in the range 0.70–0.85 [4, 5, 21]; using a midpoint value of 0.78, viscoelastic hysteresis alone accounts for approximately 39% energy loss ($1-e^2 = 1-0.61$). Snap-through instability dissipates additional energy as acoustic emission and structural vibration during inversion, estimated at approximately 7% [6, 7, 22–24]. Air drag on a low-mass ($\approx$ 5 g), low-velocity ($\approx$ 9 m/s) object contributes an estimated 3%, computed from $F_d = \frac{1}{2}\rho C_d A v^2$ with $C_d \approx 0.47$ for a hemisphere and $A \approx 5 \times 10^{-4}$ m^2 [1, 3]. Together, these mechanisms account for approximately 49% of the energy input, leaving a residual unexplained loss of roughly 9.5% that likely reflects friction between the popper and scissor-jack platform during compression, which would systematically inflate the calculated work integral.

The three poppers also showed a consistent ranking in both stiffness and launch energy: the heart-eyes popper exhibited the steepest force–displacement slope and achieved the highest mean launch GPE (0.0781 J), while the crying popper, despite being intermediate in mass at 0.0055 kg, achieved the lowest GPE (0.0611 J), with the shocked popper intermediate in both. This suggests that small variations in dome geometry and rubber composition have a larger influence on energy storage [6, 7, 22, 23] than the modest mass differences among the three designs. However, as noted above, the ANOVA ($p = 0.167$) did not confirm these differences as statistically significant; a larger number of trials per popper would be required to determine whether the ranking reflects genuine design differences or sampling variability from the manual launch procedure.

V. ACKNOWLEDGEMENTS

BD was responsible for experimental setup, data collection, data organization, and the verification of graphs and calculations. AL was responsible for verifying results, drafting results and conclusions, and incorporating necessary revisions. IS was the primary author of the abstract, introduction, and discussion sections, and was responsible for conceptual framing, verification of data and measurements, and the generation and validation of major graphs and calculations. AD assisted in data collection from video analyses. We thank several anonymous peer reviewers and we thank our classmates for their collaboration in collecting and verifying measurements, assembling the necessary materials, and contributing to the accuracy and reliability of the results.

[1] P. A. Tipler and G. Mosca, *Physics for Scientists and Engineers*, 5th ed. (W H Freeman and Company, New York, 2004).

[2] R. A. Pelcovits and J. Farkas, *Barron's AP Physics C Premium* (Kaplan North America, Fort Lauderdale, FL, 2024).

[3] W. Moebs, S. J. Ling, and J. Sanny, *University Physics*, Vol. 1 (OpenStax, Houston, TX, 2016).

[4] J. A. Simeonov, The coefficient of normal restitution for the Hertzian contact of two rough spheres colliding in a viscous fluid, Mechanics Research Communications **73**, 140 (2016).

[5] A. Sendrowicz, A. O. Myhre, I. S. Yasnikov, and A. Vinogradov, Stored and dissipated energy of plastic deformation revisited from the viewpoint of dislocation kinetics modelling approach, Acta Materialia **237**, 118190 (2022).

[6] M. Gomez, D. E. Moulton, and D. Vella, Critical slowing down in purely elastic 'snap-through' instabilities, Nature Physics **13**, 142 (2017).

[7] A. N. Gent and I. S. Cho, Surface instabilities in compressed or bent rubber blocks, Rubber Chemistry and Technology **72**, 253 (1999).

[8] D. Halliday, R. Resnick, and J. Walker, *Fundamentals of Physics*, 10th ed. (John Wiley & Sons, Hoboken, NJ, 2014).

[9] D. Brown, R. Hanson, and W. Christian, Tracker video analysis and modeling tool (2025), version 6.3.3.

[10] J. Renika, E. C. Prima, and A. Amprasto, Kinematic analysis on accelerated motion using Tracker video analysis for educational purposes, Momentum Physics Education Journal **8**, 23 (2024).

[11] M. Levine, D. Khettry, K. Coulanges, and R. A. A. Dela Rosa, Acceleration is constant during free fall, Journal of Science & Engineering **2**, 41 (2026).

[12] S. Dakwale, S. Hein, R. Wallace, and S. Yellapragada, The effect of initial vertical position on velocity at which an object strikes the ground, Journal of Science & Engineering **2**, 35 (2026).

[13] I. Sharma, B. DeMairo, and A. Liddawi, Analyzing Gallileo's distance-time relationship for rolling motion on an inclined plane, Journal of Science & Engineering **2**, 38 (2026).

[14] O. Ahmadzada, J. Pawelek, M. Butch, and T. Chung, Downward acceleration is independent of mass during free fall, Journal of Science & Engineering **2**, 44 (2026).

[15] A. Hallur, J. Chan, M. Reznik, P. Zlotnikov, and J. Tiboni, Objects fall with constant acceleration regardless of mass, Journal of Science & Engineering **2**, 53 (2026).

[16] L. Brunie, J. Kadan, E. Sobel, and T. Ramesh, Testing the independence of gravitational acceleration from mass: a comparative analysis of free-falling objects near earth's surface, Journal of Science & Engineering **2**, 50 (2026).

[17] C. R. Harris, K. J. Millman, S. J. van der Walt, R. Gommers, P. Virtanen, D. Cournapeau, E. Wieser, J. Taylor, S. Berg, N. J. Smith, R. Kern, M. Picus, S. Hoyer, M. H. van Kerkwijk, M. Brett, A. Haldane, J. F. del Río, M. Wiebe, P. Peterson, P. Gérard-Marchant, K. Sheppard, T. Reddy, W. Weckesser, H. Abbasi, C. Gohlke,

and T. E. Oliphant, Array programming with `numpy`, Nature **585**, 357 (2020).

[18] P. Virtanen, R. Gommers, T. E. Oliphant, M. Haberland, T. Reddy, D. Cournapeau, E. Burovski, P. Peterson, W. Weckesser, J. Bright, S. J. van der Walt, M. Brett, J. Wilson, K. J. Millman, N. Mayorov, A. R. J. Nelson, E. Jones, R. Kern, E. Larson, C. J. Carey, İ. Polat, Y. Feng, E. W. Moore, J. VanderPlas, D. Laxalde, J. Perktold, R. Cimrman, I. Henriksen, E. A. Quintero, C. R. Harris, A. M. Archibald, A. H. Ribeiro, F. Pedregosa, P. van Mulbregt, and SciPy 1.0 Contributors, `scipy` 1.0: fundamental algorithms for scientific computing in Python, Nature Methods **17**, 261 (2020).

[19] J. D. Hunter, `matplotlib`: a 2D graphics environment, Computing in Science & Engineering **9**, 90 (2007).

[20] R. Larson and R. P. Hostetler, *Calculus*, 8th ed. (Brooks Cole, Pacific Grove, CA, 2005).

[21] B. N. J. Persson, Rubber friction: role of the flash temperature, Journal of Physics: Condensed Matter **18**, 7789 (2006).

[22] Y. Forterre, J. M. Skotheim, J. Dumais, and L. Mahadevan, How the Venus flytrap snaps, Nature **433**, 421 (2005).

[23] S. Timoshenko and J. M. Gere, *Theory of Elastic Stability*, 2nd ed. (McGraw-Hill, New York, 1961).

[24] A. F. Arrieta, P. Hagedorn, A. Erturk, and D. J. Inman, A piezoelectric bistable plate for nonlinear broadband energy harvesting, Applied Physics Letters **97**, 104102 (2011).