PY413 Thermal Education and Research Laboratory (EaRL) Spring 2026 H

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Introduction

This is Group 9's report for the Thermal Physics Spring 2026 EaRL in the Classroom. The report details the phenomenon of unexpected temperature change in entropic springs resulting from the first two laws of thermodynamics, records a series of lab observations of a rubber band's changing entropy and temperature, provides an explanation of theory and models to explain the observations, and then poses a series of questions and answers to provide further analysis of the systems under investigation.

Contents

1   Theory I: Entropic Elasticity in Rubber

The tension force generated when you stretch something can be complicated. However, a good first-order model for relatively small displacements in most materials is Hooke's Law:

$$F = -kx$$

where F is the restorative force, k is the stiffness, and x is the displacement.

For elastic polymeric materials, the "spring constant" is related to the entropy. As Schroeder explains, "Polymers, like rubber, are made of very long molecules, usually tangled up in a configuration that has lots of entropy."

These long molecules have stiff segments (like links in a chain) but can otherwise collapse and fold. In a solid, the chains are both "relaxed" (collapsed/folded) and entangled with each other. When you pull on the clumped-up chains, some elongate, reducing the configurational entropy. Type stuff in here.
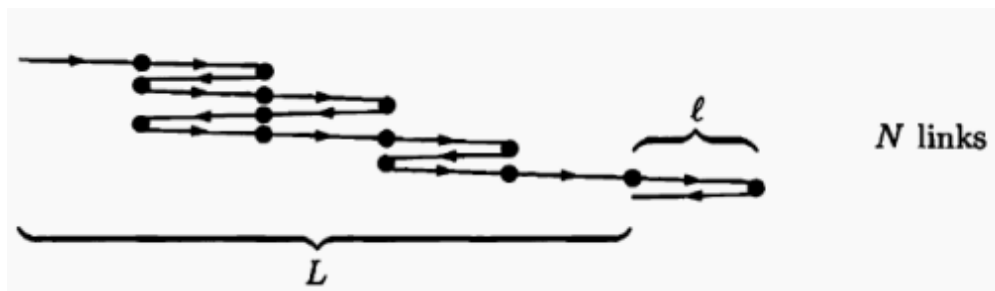

Figure 1: A crude model of a polymer chain where each link (length ℓ) can only point left or right. (Based on Schroeder, Fig 3.17).

Schroeder describes a model where if you pulled the chain taut, its length would be $L = N\ell$. However, in real materials, the chains are much shorter ($L \ll N\ell$) and tangled. In the "relaxed" case, chains have many possible configurations and thus greater entropy.

Thermodynamic Consequences

Consider the sudden stretching of a rubber band. Because the change is quick, the band does not exchange heat with the environment ($Q = 0$). However, the entropy associated with the configuration decreases because chains are stretched out.

Due to the Second Law of Thermodynamics, $\Delta S_{\text{net}} \geq 0$. Therefore, the entropy due to thermal fluctuations must increase by at least as much as the configurational entropy decreased. This is achieved by a change in temperature.

2   Experiment I: Rapid Elongation

Setup and Safety

1. **Safety:** Put on safety glasses.

2. **Load Sample:** We use an Instron Material Testing System (Figure 2). Follow the TA's instructions to load the rubber sheet into the clamps.

3. **Software Setup:** Open "Bluehill 3".

   - Use manual controls ("Jog Down") to make the rubber slightly slack.
   - Press "Balance Load" and "Zero Extension" to zero the instrument.

4. **Thermometer Practice:** Practice using the IR thermometer on objects in the room. Note that it takes a few seconds to get an averaged reading.
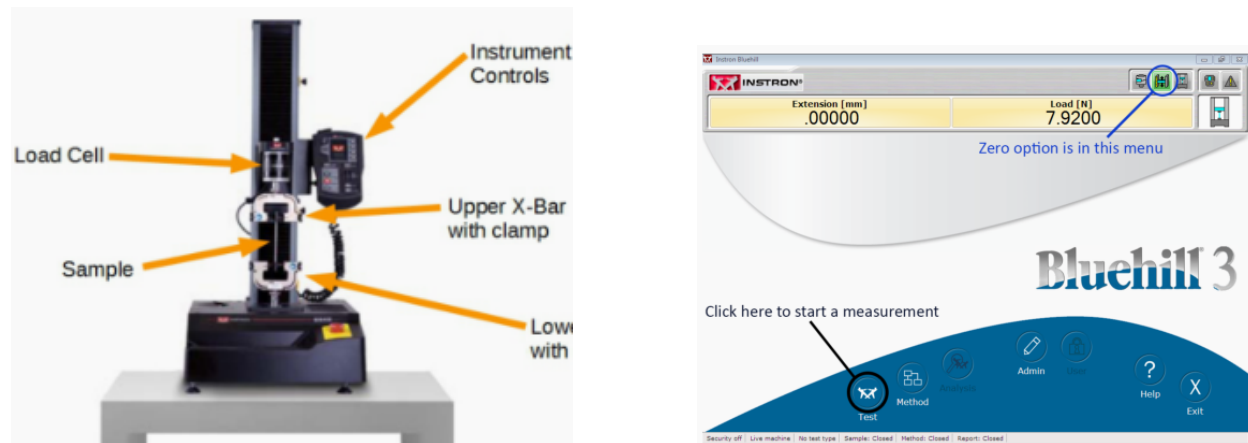

Figure 2: Left: The Instron tensile tester. Right: The Bluehill software interface.

Measurement Procedure

5. **Select Method:** Click "Test" and select a method starting with `PY413_RapidStretch` followed by a speed.

6. **Filename:** Save as `GroupX_rapid_stretch_[speed]`.

7. **Measure:**

   (a) Record the **Initial Temperature** (unstretched).
   (b) Take picture of unstretched sample (3)
   (c) Click "Start". Keep the IR thermometer on the rubber.
   (d) Record the **End Temperature** immediately after the cross-bar stops.
   (e) Press "Return" to relax the sample.

8. **Repeat:** Perform this three times with fresh samples, changing the speed each time.

Table 1: Experimental observations for rapid stretching.

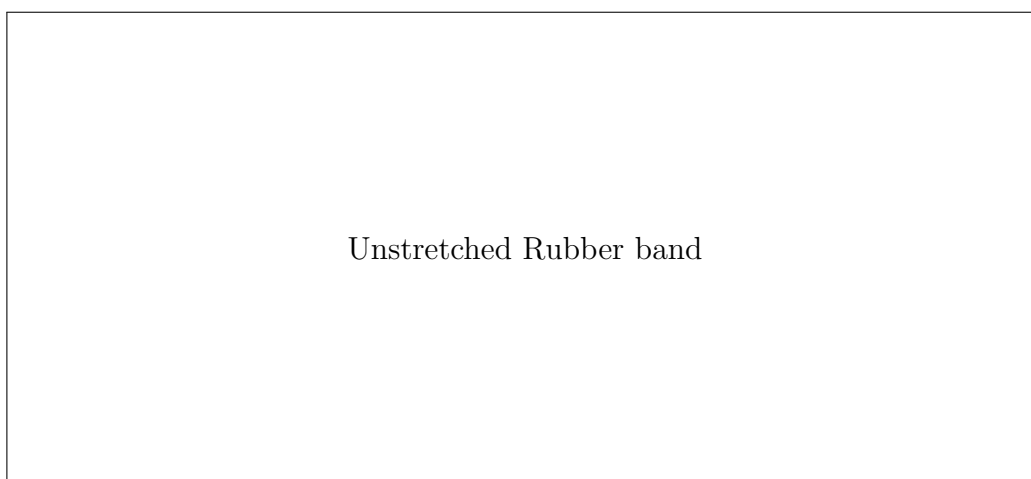| Band Width: ___		Band Thickness: ___			
Trial	**Speed**	**Temp Initial**	**Temp Final**	**Length Initial**	**Length Final**
1					
2					
3					

Unstretched Rubber band

Figure 3: A picture of our rubber band in the tensile testing apparatus, unstretched.

Questions (To be turned in)

A) Graph the force vs. temperature for each speed. Assume temperature increases linearly during stretching. Label axes clearly.

Solution: Solution A Here.

```
1  if __name__ == "__main__":
2      break
```

Listing 1: Code for Solution A Graphs

B) Explain your observations. Why are the results from the trials different or the same?

Solution: Solution B Here.

C) Explain the theoretical reasoning for why the temperature should increase based on thermodynamic principles. How do your results support this?
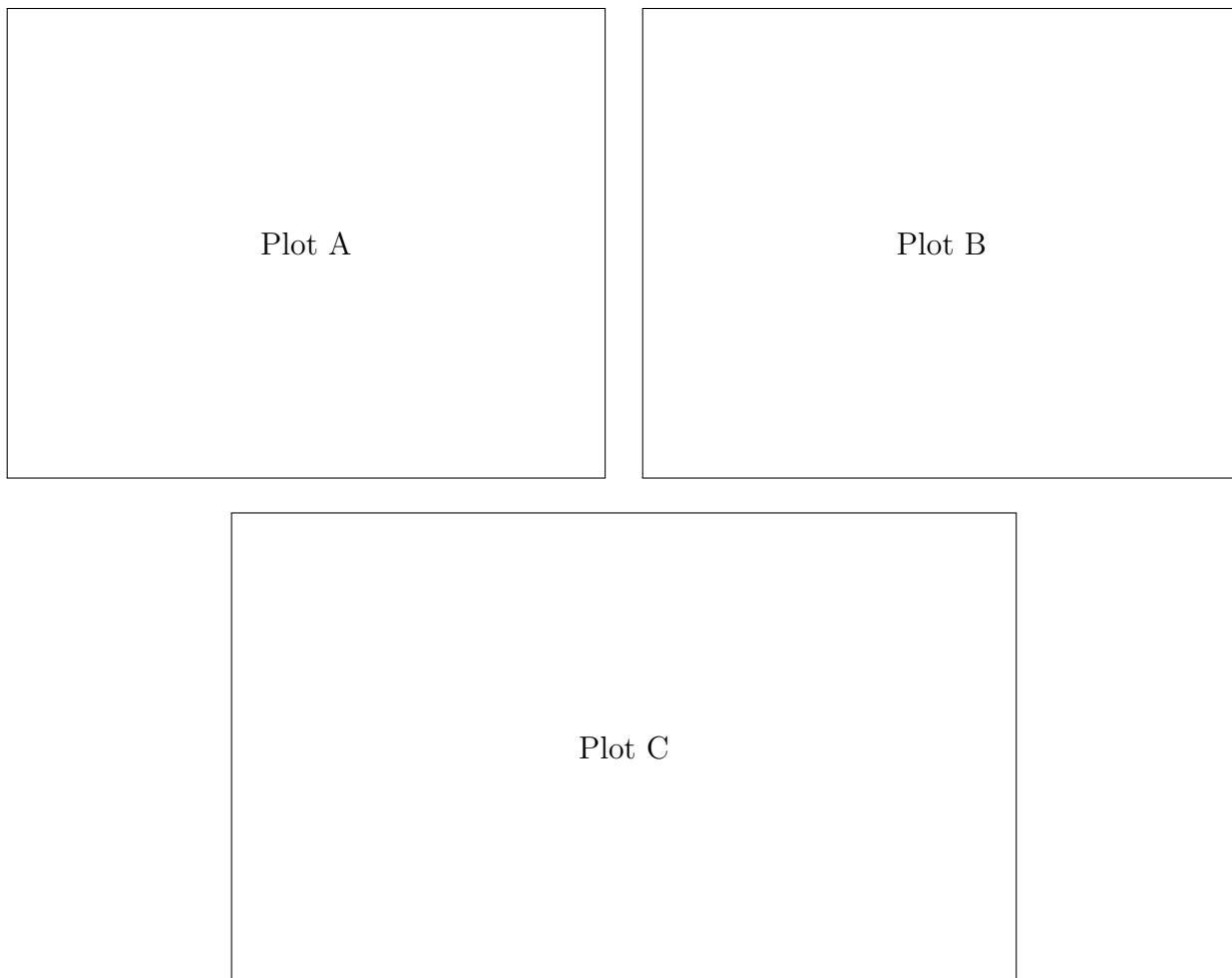
Solution: Solution C Here.

Figure 4: Force vs. Temperature Graph For Each Speed

3 Theory II: Temperature Dependence of Spring Constant

For small changes, the First Law of Thermodynamics states:

$$dU = dQ + dW \tag{1}$$

The relationship between heat (Q) and entropy (S) is:

$$dQ = TdS \tag{2}$$

For isothermally stretching a rubber band of length L, the work done on the rubber is:

$$dW = \langle F \rangle dL \tag{3}$$

Combining Equations 1–3 where $\langle F \rangle$ is the average force exerted by the material as it is stretched from length L to length $L + dL$:

$$\langle F \rangle dL = dU - TdS \tag{4}$$

Schroeder argues that entropy is a function of band length length L (see 1) and temperature:

$$S = S(L, T) \tag{5}$$

We further assume internal energy depends only on temperature independently of extension L:

$$U = U(T) \implies \left(\frac{\partial U}{\partial L}\right)_T = 0 \tag{6}$$

Question (To be turned in)

D) With these assumptions, the tension force can be expressed in terms of a partial derivative of entropy and temperature. Derive this expression starting from Eq. 4. Call this **Equation (7)**. (In working Schroeder problem 3.34 one can derive a more complete version of equation 7 which shows both the linearity with L, the spring part, and the linearity with T, the entropic spring part).

Solution: Solution D Here.

4   Experiment II: Temperature Dependence of Tension

We will place the rubber in a stretched state (holding L constant), allow it to cool, and then observe the dependence of tension on temperature.

Procedure

5. **Setup:** Use the last sample from Experiment I. Ensure it is unstretched.

6. **Method:** Select `PY413_stress_relaxation.im_tens`.

7. **Protocol:**

   - The machine will stretch to $28.5\,\text{N}$, then slowly to $30\,\text{N}$.
   - It then holds length constant (Stress Relaxation).
   - **Measurement 1 (No Heat):** Allow the rubber to relax naturally for several minutes without heating. Monitor the force decay.
   - **Measurement 2 (With Heat):**
     (a) Wait for rubber to cool to the unstretched temperature.
     (b) Use the heat gun (lowest setting) to heat the rubber to a target between $23\,°\text{C}$ and $40\,°\text{C}$.
     (c) **Do not exceed** $40\,°\text{C}$.
     (d) Remove heat immediately, record the peak temperature and time.
     (e) Let it cool, then repeat for a different target temperature.

Table 2: Data analysis for force as a function of temperature.

Initial Unstretched Temperature: _____						
Trial	Time	Max Temp	Δ Temp	Peak Force	Expected Force (No Heat)	Δ Force
1	t_1					
2						
3						
4						

Analysis and Questions (To be turned in)

E) Graph **Force vs. Time** for Measurement 1 and Measurement 2. Label axes and the two graphs clearly.

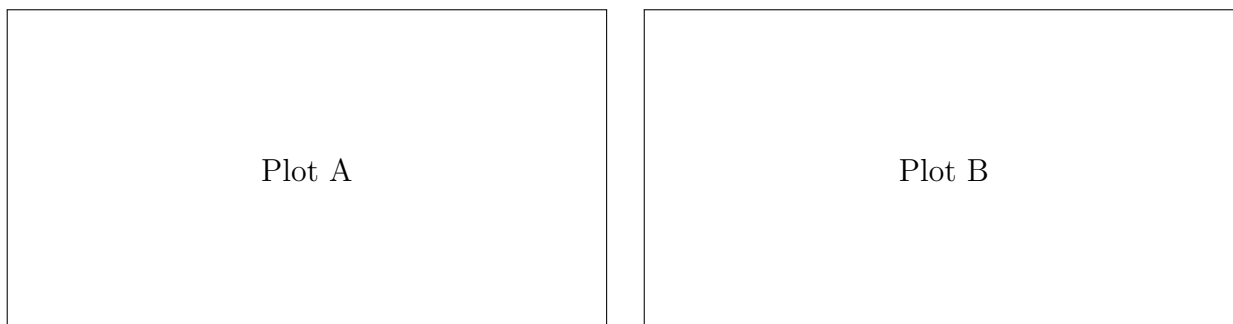**Solution:** Solution E Here.

Figure 5: "Force vs. Time Graphs for Measurement 1 and Measurement 2"

```
1  if __name__ == "__main__":
2      break
```

Listing 2: Code for Solution E Graph

F) Fill out Table 2. Identify the "heating peaks" in Measurement 2. Compare the Peak Force to the "Expected Force" (baseline from Measurement 1 at that specific time). Calculate ΔF.

Solution: Solution F Here.

G) Plot ΔF vs ΔT. Apply a linear fit. Turn in this graph, including the fit equation and R^2 value.
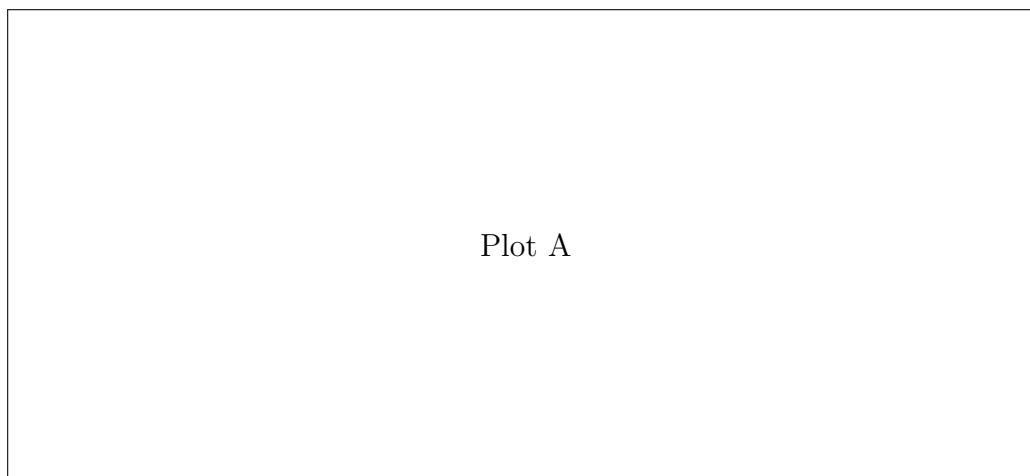
Solution: Solution G Here.

Figure 6: "Change in Force vs. Change in Temperature Graph"

```python
if __name__ == "__main__":
    break
```

Listing 3: Code for Solution G Graph

H) The theory relies on the assumption $L \ll N\ell$. How could you change the experiment to test this assumption?

Solution: Solution H Here.

I) What are the conditions/limits for the force law derivation (Equation 7), and are they consistent with this experiment?

Solution: Solution I Here.

References

[1] M. Euler. "Hooke's law and material science projects: exploring energy and entropy springs". *Phys. Edu.*, 2008, 43: 57-61.

[2] G. Marx, J. Ogborn and P. Tasnadi. "Rubber as a medium for teaching thermodynamics". *Euro. J. Phys.*, 1984, 5 (4): 232-237.

[3] Daniel V. Schroeder. *An Introduction to Thermal Physics.* San Francisco: Addison-Wesley (2000).

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