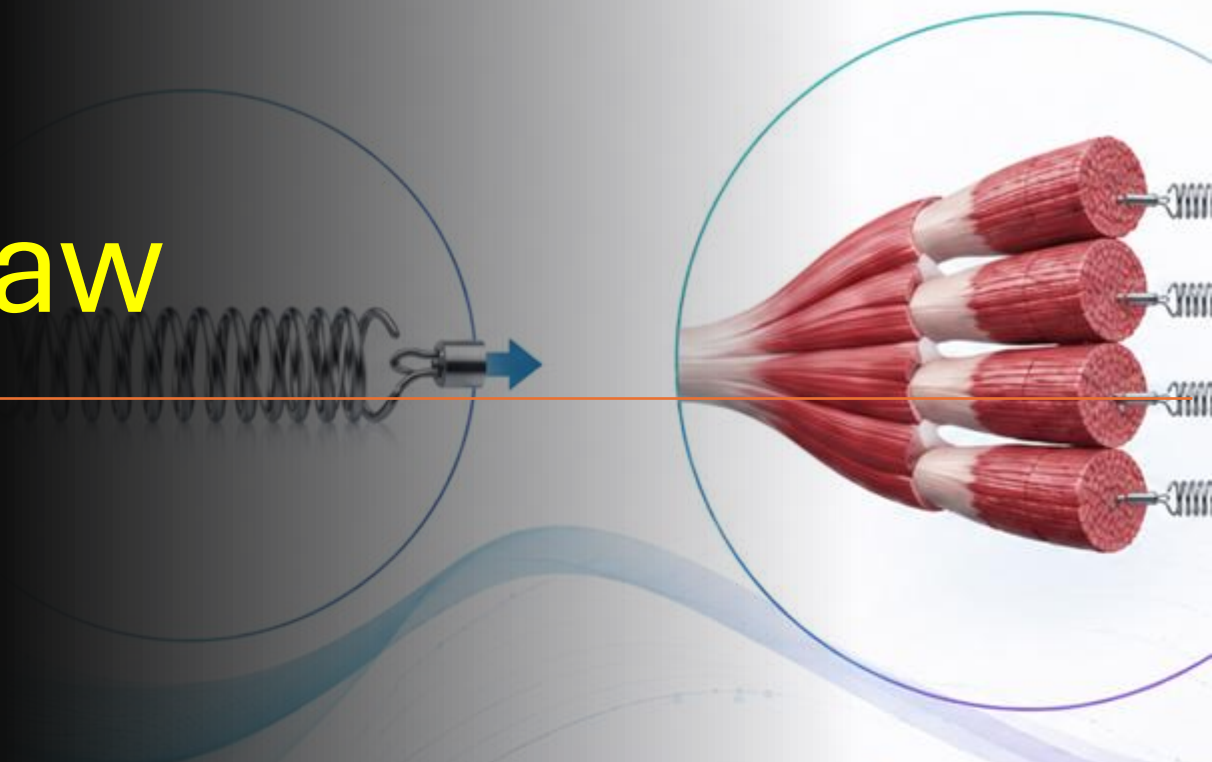
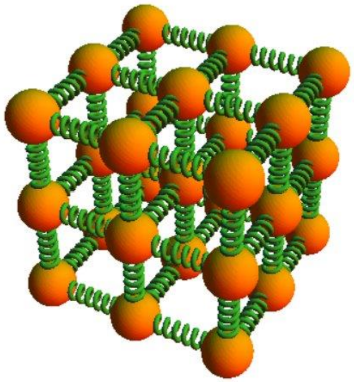
Hooke's Law

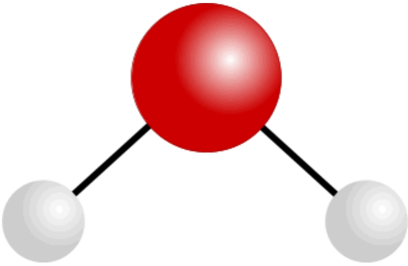
Modeling muscles
and chemical
bonds as springs

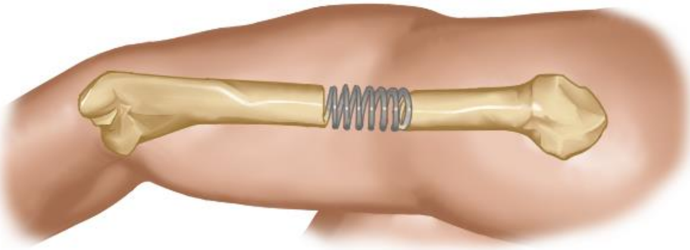


Abhishek C P
06/26/2026

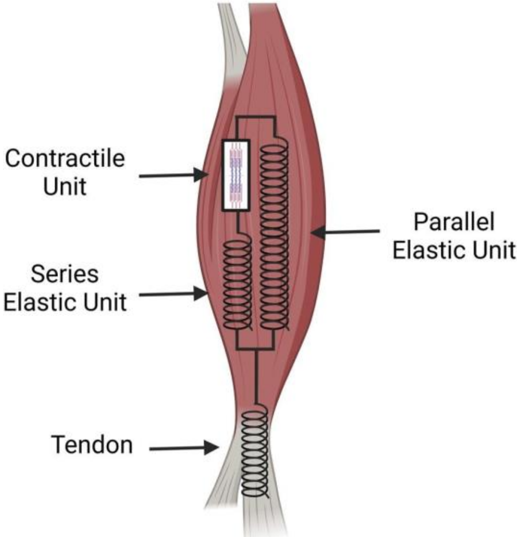
WHY SPRINGS ?



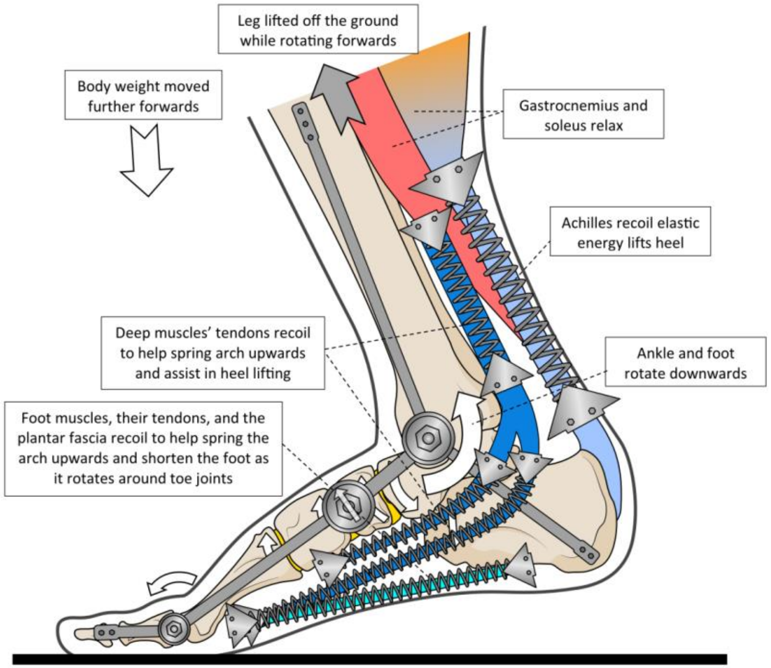




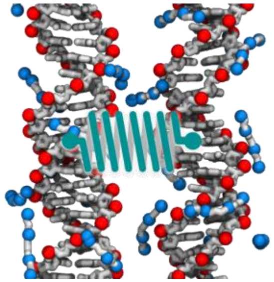
https://phys.libretexts.org/Bookshelves/Conceptual_Physics/Body_Physics_-_Motion_to_Metabolism_(Davis)/07%3A_Strength_and_Elasticity_of_the_Body/7.06%3A_Modeling_Body_Tissues_as_Springs



Frontiers | The musculotendinous interface: insights into development, injury, and recovery for military medical applications



https://www.healthystep.co.uk/advice/calf-length-foot-pump-socks-for-calf-strains-and-achilles-pain/

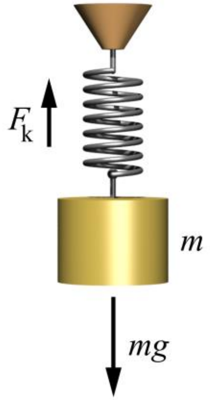


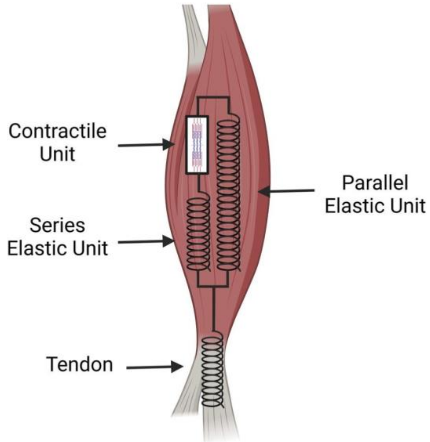
https://bionano.physics.illinois.edu/node/212

TWO WAYS TO STUDY SPRINGS

TODAY	NEXT CLASS

Static Case: Springs under force

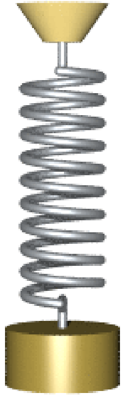


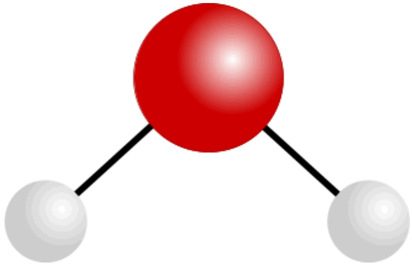


We ask : How much does it stretch?

Muscle Fibers, DNA stretching, Chemical bonds

Dynamic Case: Springs in motion





We ask : How fast does it oscillate?

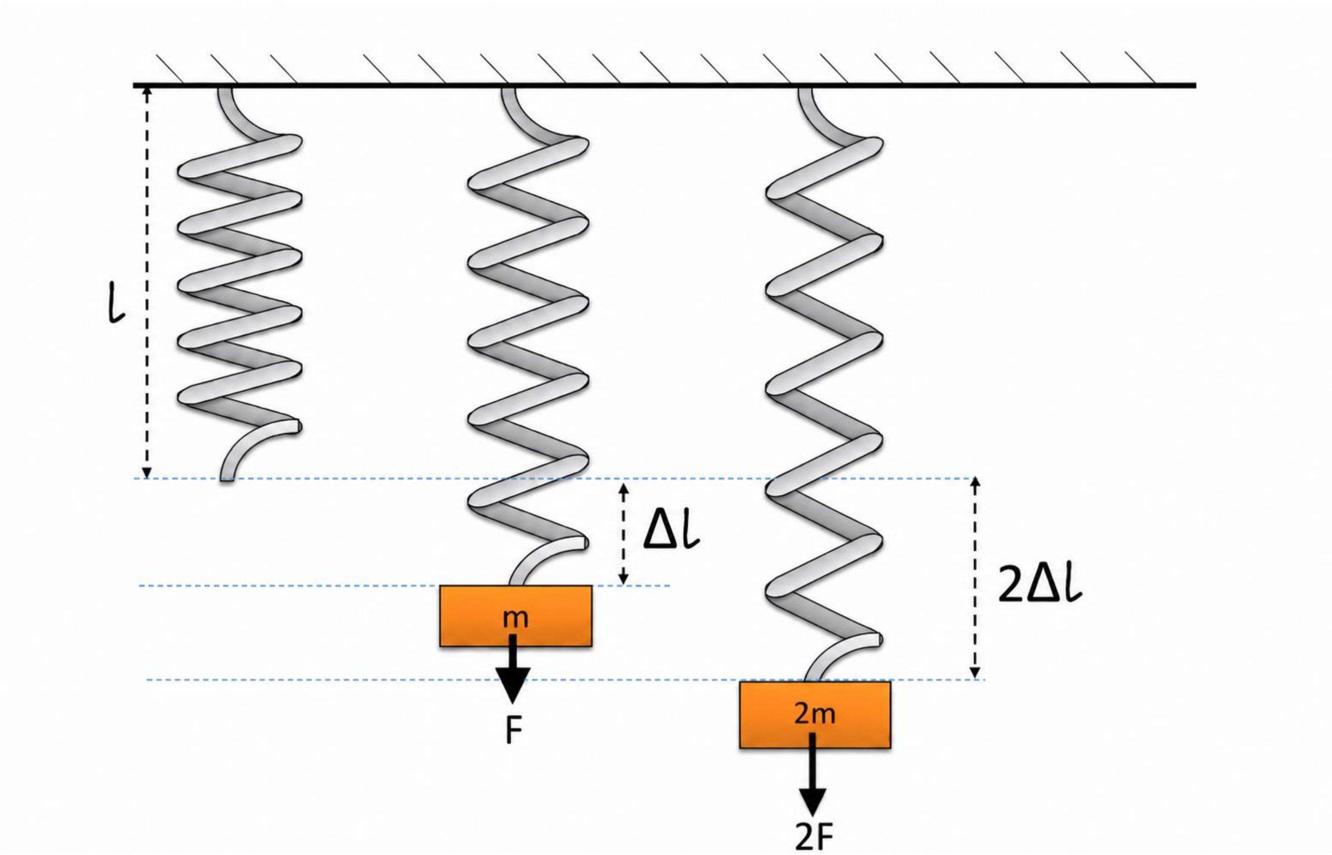
Simple harmonic motion, Molecular vibrations, and basics of IR spectroscopy

https://commons.wikimedia.org/wiki/File:Animated-mass-spring.gif

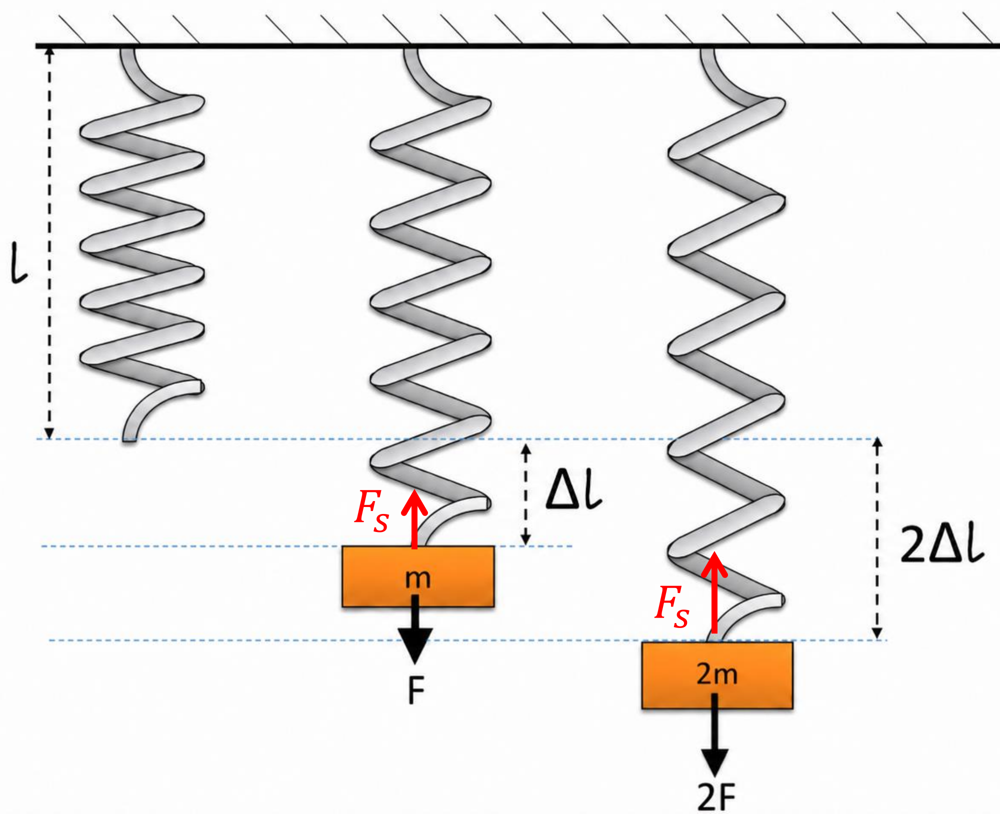
LEARNING GOALS

- Explain what the spring constant (k) means physically.
- Compare springs in series and in parallel.
- Connect the model to muscle fibers

HOOKE'S LAW



HOOKE'S LAW



$$\vec{F_s} = -k\,\overrightarrow{\Delta l}$$

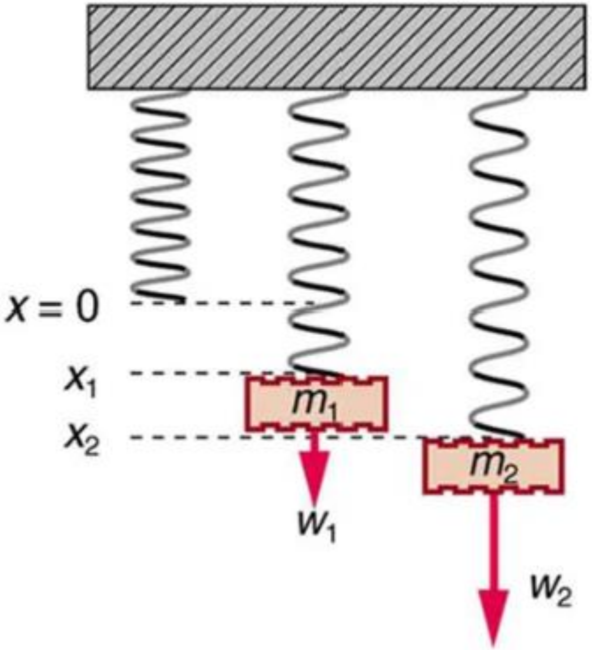
$\vec{F_s}$ – Restoring force or Spring force

Δl – Change in length

k – Stiffness/Spring constant

Hooke's law states that the force needed to stretch or compress a material is directly proportional to the extension or compression of the material from its natural length.

SPRING CONSTANT- LAB



m (kg)	w (N) F	x (m) Δl
0.000	0.00	0.000
0.100	0.98	0.025
0.200	1.96	0.050
0.300	2.94	0.076
0.400	3.92	0.099
0.500	4.90	0.127

? What would be the shape of the graph if we plot F along the y-axis and change in length (Δl) along the x-axis

SPRING CONSTANT- LAB

m (kg)	w (N)	x (m) (Δl)
0.000	0.00	0.000
0.100	0.98	0.025
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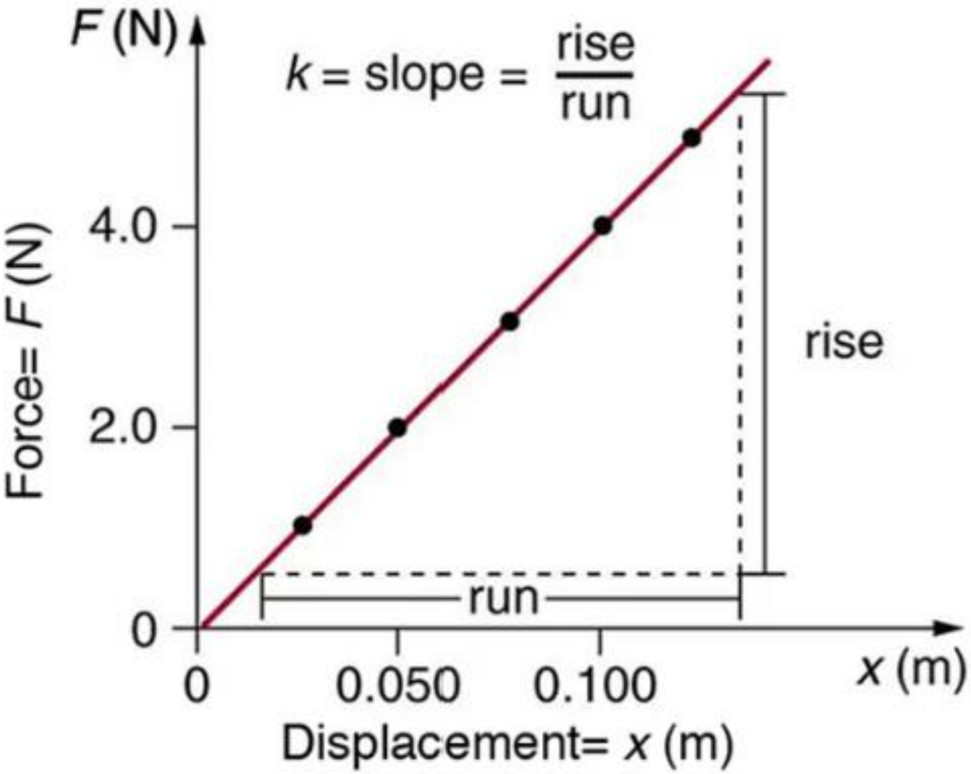
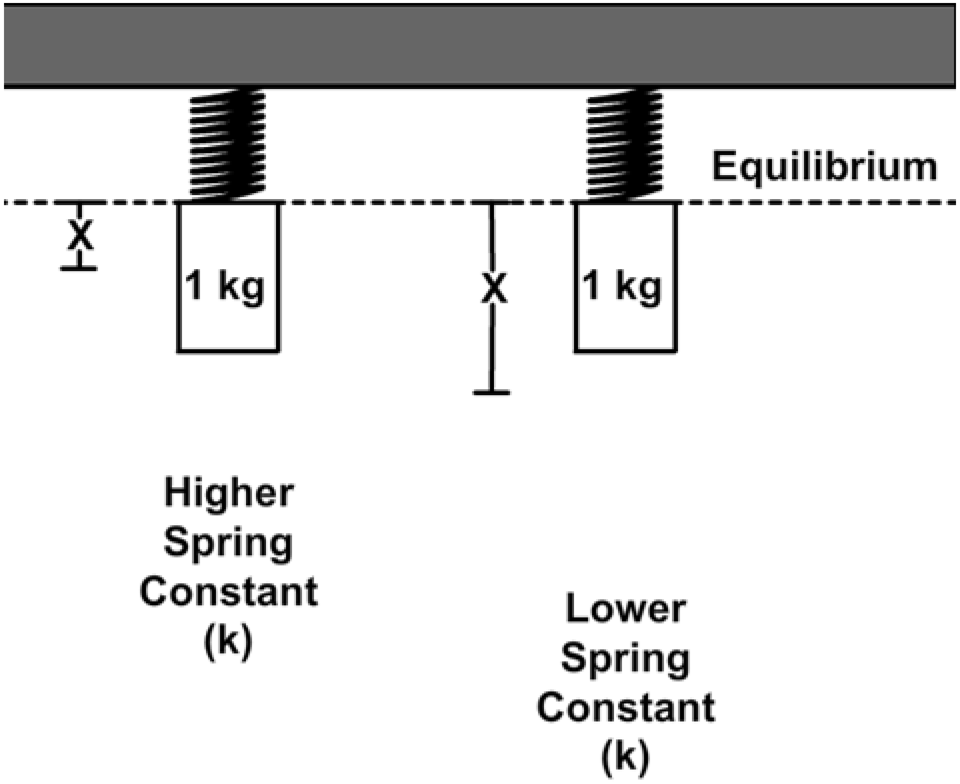
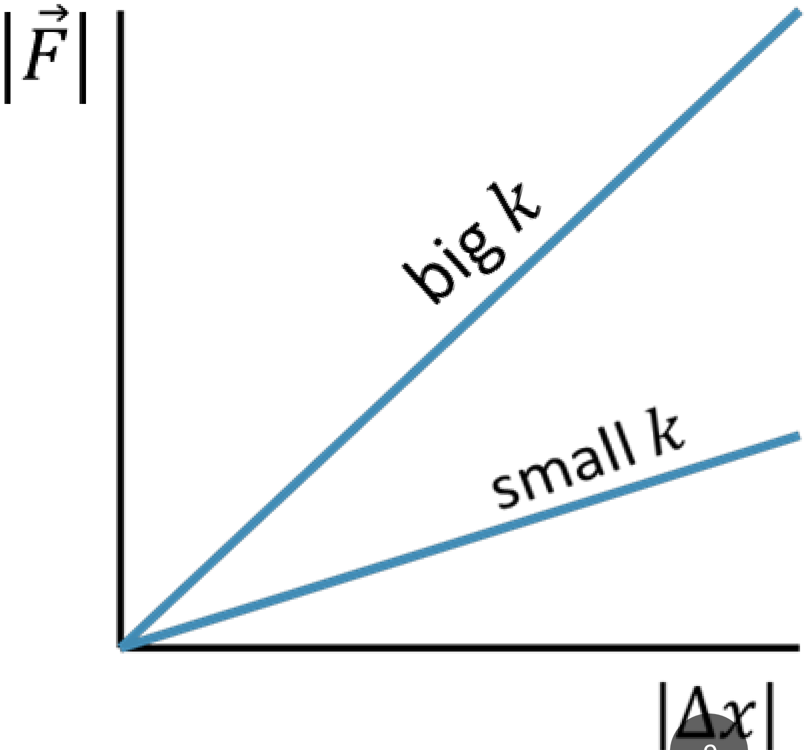


Spring constant $= \frac{|F|}{|\Delta l|}$ = slope of F vs displacement graph

The **higher the spring constant, the stiffer the spring**,
⇒ the less it will stretch under the same force

$|F_s| = k\,|\Delta l|$





(Think-Pair-Share) TPS- QUESTION 1

A spring obeys Hooke's law. When you stretch the spring $2\ cm$, the spring pulls on you with a force of $10\ N$. When you stretch the same spring $4\ cm$, the spring pulls on you with a force of

$$|F_s| = k\ |\Delta l|$$

1) $10\ N$
2) $20\ N$
3) $40\ N$
4) $5\ N$
5) $2.5\ N$

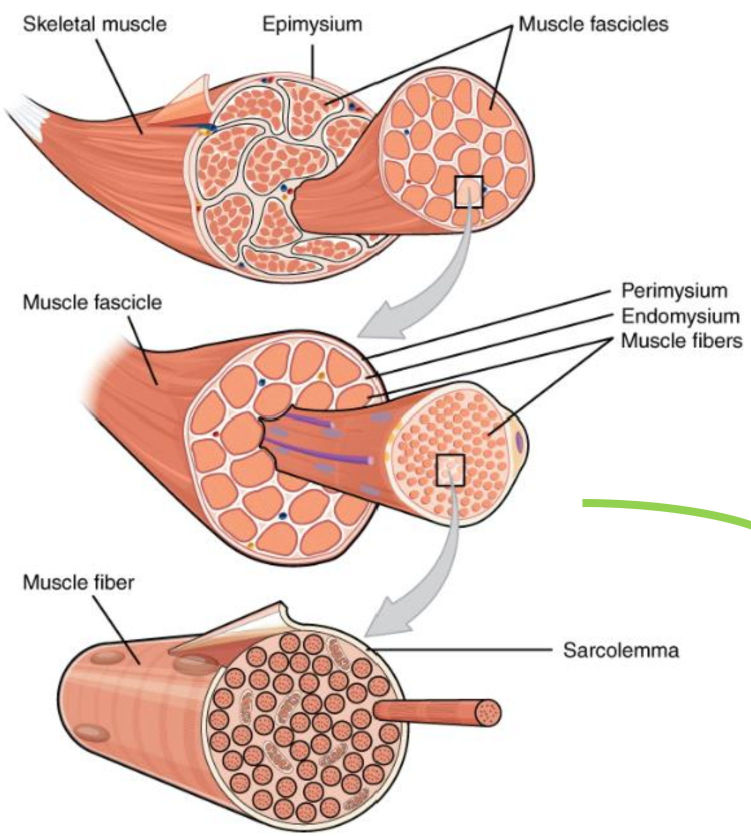
TPS-QUESTION 2

Which of the statements below is true for a spring that is very stiff?

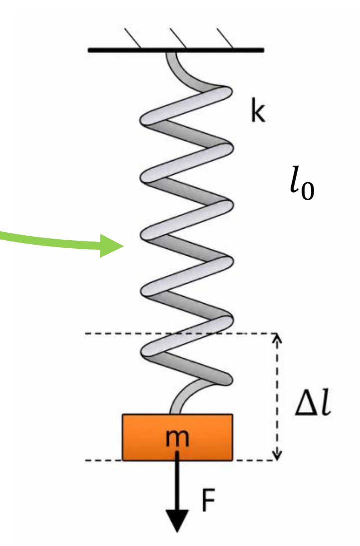
1. The spring will stretch a large distance even when pulled with a small force.
2. The line on a graph of force vs. spring length would be very steep (more than 45 degrees above horizontal).

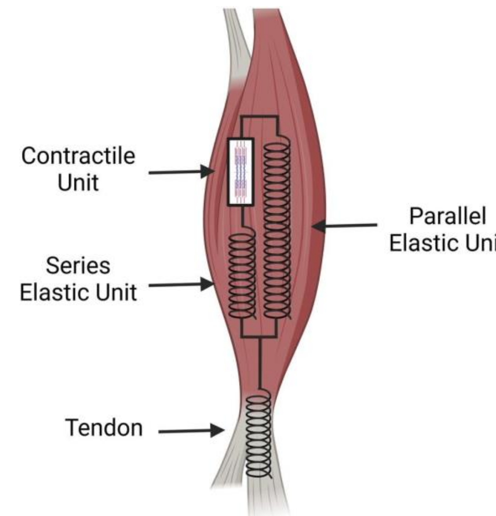
1) Only 1.
2) Only 2.
3) Both 1. and 2.
4) Neither 1. nor 2.

TOY MODEL OF A MUSCLE



We'll take as our basic element a single spring (model of a fiber)





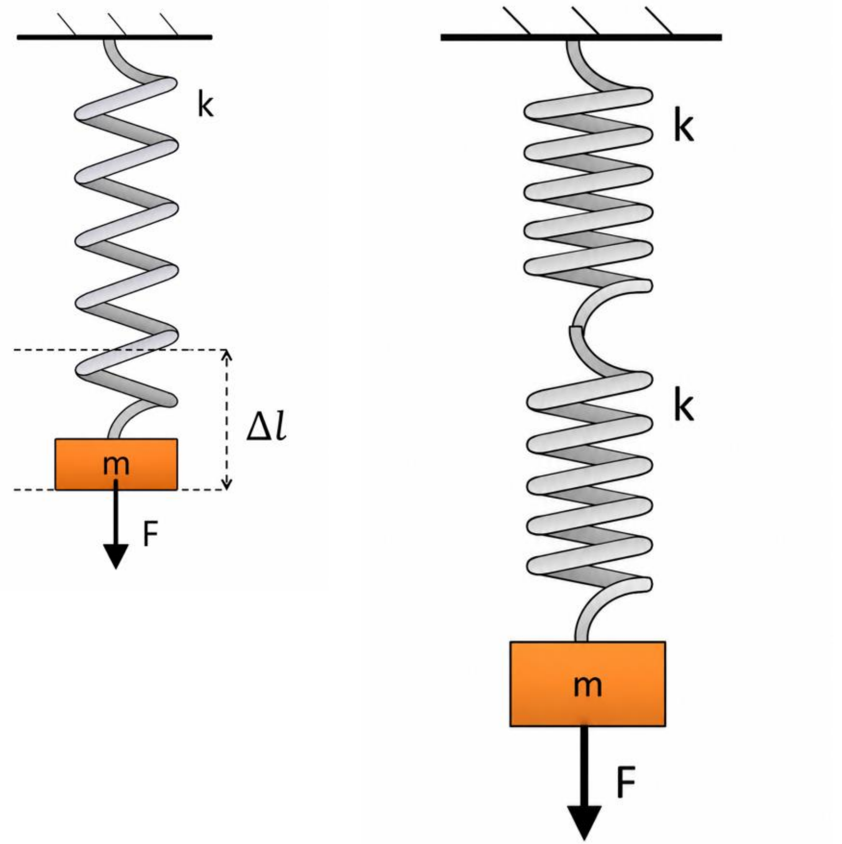
https://courses.lumenlearning.com/suny-ap1/chapter/skeletal-muscle/

https://www.compadre.org/nexusph/course/Stretching_multiple_springs_-_toy_model_of_a_muscle

TPS-SPRINGS(fibers) IN SERIES

A single spring is pulled by a force F, causing it to stretch a distance of Δl. A second identical spring is attached to the end of the first spring. The same force F is now applied to the ends of the joined springs. What is the total distance (ΔL) the joined springs will stretch?

1) $4\Delta l$
2) $2\Delta l$
3) Δl
4) $\Delta l/2$
5) $\Delta l/4$
6) None of the other choices



Link to PhET simulation

SOLUTION

- A single spring is pulled by a force F, causing it to stretch a distance of Δl. A second identical spring is attached to the end of the first spring. The same force F is now applied to the ends of the joined springs. What is the total distance (ΔL) the joined springs will stretch?

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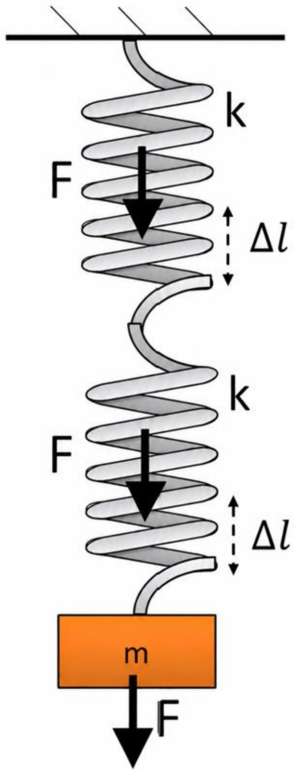


$$\Delta L = \Delta l + \Delta l$$

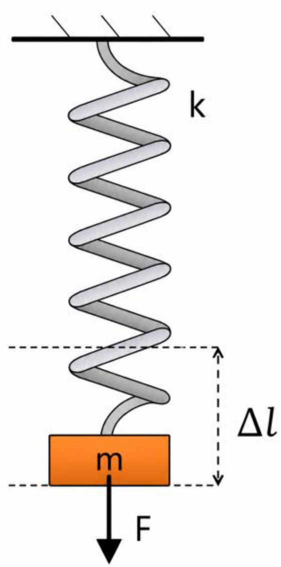
Series connection makes the system **STRETCHIER/FLEXIBLE**

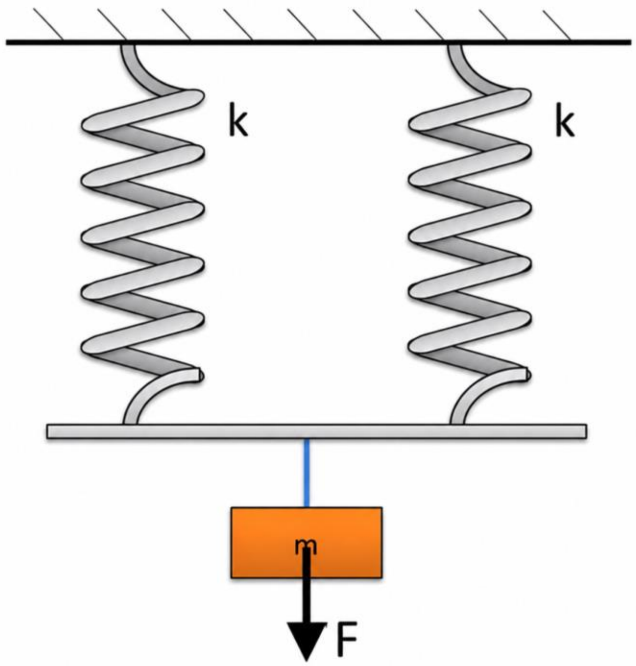
Link to PhET simulation

TPS-SPRINGS IN PARALLEL

Let's consider the effect of linking fibers to the same connecting point on either end (parallel connection). Consider the same two identical springs each having spring constant k, but this time with both linked at each end to the same object. The same force F is now applied to the ends of the joined springs. What is the total distance the joined springs will stretch?

1) $4\Delta l$
2) $2\Delta l$
3) Δl
4) $\Delta l/2$
5) $\Delta l/4$
6) None of the other choices



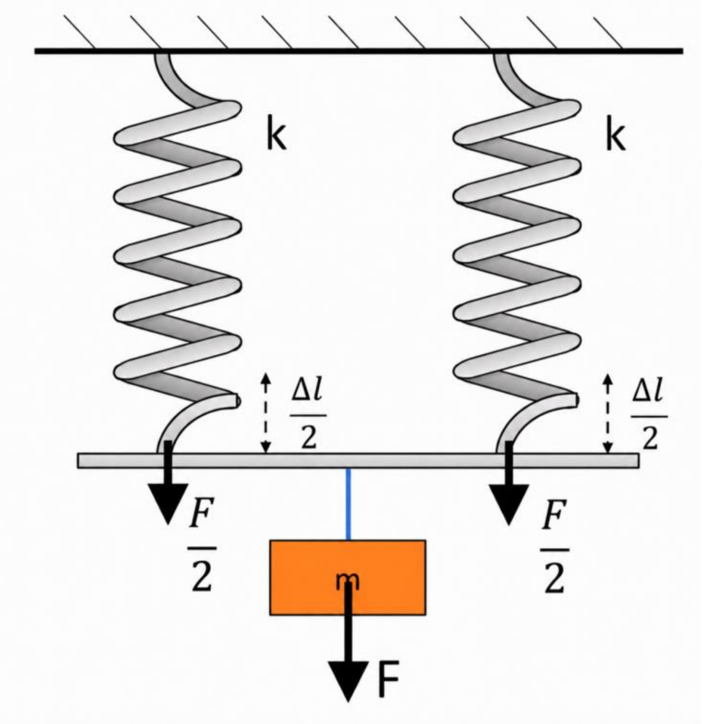


Link to PhET simulation

SOLUTION

Let's consider the effect of linking fibers to the same connecting point on either end (parallel connection). Consider the same two identical springs each having spring constant k, but this time with both linked at each end to the same object. Equal tension forces F are applied to the objects connecting the springs together. What is the total distance the joined springs will stretch?

1) $4\Delta l$
2) $2\Delta l$
3) Δl
4) $\Delta l/2$
5) $\Delta l/4$
6) None of the other choices



$$\Delta L = \Delta l/2$$

parallel connection makes the system **STIFFER**

[Link to PhET simulation]

TPS-QUESTION 3

In the human body, the distance that muscles can stretch is limited by the size and range of motion of the body. If we assume that the maximum stretching distance of a muscle is fixed, then

Which is more desirable for the ability to lift heavier objects: a large effective spring constant or a small effective spring constant?

What does this imply about the way that muscles are built in the body?

TPS-QUESTION 4

During walking, the tibia can experience forces as large as 4.7 times your body weight[1]. If we model the tibia as a spring with a spring constant of $4.7 \times 10^7\ N/m$. how much does the tibia compress $(\Delta l\ )$ under this maximum force? Assume the person weighs 750 N (approximately 75 kg).

$$|F| = k\ |\Delta l|$$

[1] Internal loads in the human tibia during gait, Clinical Biomechanics, 2009

SOLUTION

During walking, the tibia can experience forces as large as 4.7 times your body weight[1]. If we model the tibia as a spring with a spring constant of $4.7 \times 10^7\ N/m$. how much does the tibia compress $(\Delta l\ )$ under this maximum force? Assume the person weighs 750 N (approximately 75 kg).

Step 1 : Read the question

Step 2 : List out the quantities given

$$Weight = 750\ N$$

$$F = 4.7 \times Weight = 4.7 \times 750\ N$$

$$k = 4.7 \times 10^7\ N/m$$

Step 3 : Write down the quantity that is unknown

$$\Delta l = ?$$

Step 4 : Identify the equation that relates the known quantities to the unknown.

$$|F| = k\ |\Delta l| \qquad \Delta l = \frac{F}{k}$$

Step 5 : substitute everything

$$\Delta l = \frac{4.7 \times 750\ N}{4.7 \times 10^7\ \ N/m}$$

$$= \frac{750}{10^7} = 750 \times 10^{-7}\ \ m$$

$$= \ 75 \times 10^{-6}\ \ m$$

$$= \ 75\ \ \mu m$$

(About the size of human hair)

Step 6 : Does the answer make physical sense?

Yes. The tibia compresses only about 75 µm (0.075 mm), showing that bone is extremely stiff.

KEY TAKEAWAYS FOR THE DAY

1 . Hooke's law connects force and stretch/compression

$$|F_s| = k\ |\Delta l|$$

2. Spring constant k measures the stiffness

3. Arrangement of spring matters

Spring in series → stretchier → Small effective spring constant

Spring in parallel → Stiffer → Large effective spring constant

4. Hooke's law is a first model for real biological and molecular system

Parallel arrangement helps with force. Series arrangement helps with length change and range of motion. Real muscles balance both depending on what the body part needs to do.

TPS- EXIT QUESTION

A chemical bond is not literally a metal spring. But near equilibrium, a bond behaves approximately like a spring.

Q : Which bond is harder to stretch: a C-C single bond or C=C double bond?

THANK YOU

Any questions? Email me at : *abhishekcp.research@gmail.com*

Link to PhET simulation

Link to Physics For Life-science Resource

Link to OpenStax College Physics textbook

about Robert Hooke

Scan the QR code for slides

Teaching Experience

Wayne State University (2021–Present)

- Physics for Life Sciences I & II
- University Physics I & II
- Physics for Life Sciences Laboratory
- Descriptive Astronomy Laboratory
- Instructor of Record – Physics for Life Sciences I (Summer 2026)

My Teaching Philosophy

Every student can learn physics

Every student is capable of learning physics when given sufficient guidance, practice, encouragement, and the opportunity to grow. My goal is to help students build confidence in their abilities while developing a strong conceptual understanding of the subject.

"*He was terrific. His understanding of Physics allowed him to break it down in simple terms and make any difficult problems very understandable. It was easy to do well with him helping.*"

(selected comments from Wayne State University Student Evaluation of Teaching)

My Teaching Philosophy

Through Productive Struggle

I believe mistakes are an essential part of learning. I encourage students to attempt problems independently before providing guidance, because productive struggle often leads to deeper understanding. My role is to ask questions, offer hints, and guide students toward the solution rather than simply providing the answer.

"Abhishek took a very good approach... allowing us to try and solve the problems alone, and if we couldn't, he would guide us to the right answer or the right steps, telling us them outright only as a last resort. His discussion section gave us a great way to assess our understanding of the material and where we were struggling."

(selected comments from Wayne State University Student Evaluation of Teaching)

My Teaching Philosophy

Challenge with compassion

I maintain high expectations for every student while recognizing that they come from different educational backgrounds, experiences, and levels of preparation. Rather than lowering expectations, I strive to provide the support each student needs to reach them.

"He is a fine teacher for the class. He goes around to make sure everyone is on track, and he sits down extensively for you to understand what ever problem you are trying to tackle."

(selected comments from Wayne State University Student Evaluation of Teaching)

My Teaching Philosophy

A classroom built on kindness

Students learn best when they feel comfortable asking questions, making mistakes, and participating in class. I strive to create a respectful, welcoming, and inclusive learning environment where students feel supported, valued, and confident enough to be curious.

"Never made me feel dumb for asking questions."

"Abhishek, thank you so much for the amazing semester. I appreciate how understanding, respectful, and kind you always remained."

I put these principles into practice by connecting physics to real-world examples, encouraging active participation, and helping students develop confidence through understanding rather than memorization.

(selected comments from Wayne State University Student Evaluation of Teaching)