Springs

Unit: Forces in One Dimension

NGSS Standards/MA Curriculum Frameworks (2016): N/A

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): 2.8.A, 2.8.A.1, 2.8.A.2, 2.8.A.3

Mastery Objective(s): (Students will be able to…)

- Set up and solve problems involving springs.

Success Criteria:

- Expressions involving springs are correct including the sign (direction).
- Algebra is correct and rounding to an appropriate number of significant figures is reasonable.

Language Objectives:

- Explain the direction of the force applied by a spring.

Tier 2 Vocabulary: spring

Notes:

spring: a device made of an elastic, but rigid material (usually metal) bent into a form (often a coil) that can return to its natural shape after being extended or compressed.

equilibrium position: the position of an object attached to a spring when there is no force on it.

closed coil spring (tension spring): a spring whose coils are touching when the spring is in its equilibrium position. A closed coil spring can be extended but cannot be compressed.

open coil spring (compression spring): a spring whose coils are not touching when the spring is in its equilibrium position. An open coil spring can be either extended or compressed. Unless otherwise specified, assume that all springs are open coil springs.

spring force (F_s): the force exerted by a spring as it attempts to return to its natural shape.

The spring force is a reaction force that is caused by the force that displaces the spring from its equilibrium position.

Use this space for summary and/or additional notes:

spring constant (k): the amount of force needed to extend or compress a spring a specific distance (measured in $\frac{\text{N}}{\text{m}}$).

The larger the spring constant, the more force is needed to extend or compress the spring. For example, a Slinky has a spring constant of $0.5\,\frac{\text{N}}{\text{m}}$, while a heavy garage door spring might have a spring constant of $500\,\frac{\text{N}}{\text{m}}$.

Note that ***the spring constant is specific to an individual spring***, not just the material that it is made of. For example, if the length of a spring were cut in half, its spring constant would be doubled.

ideal spring: a spring that has negligible mass and that exerts a force proportional to its change in length.

For an ideal spring, the spring force is given by Hooke's law, named for the 17th-century British physicist Robert Hooke:

$$\vec{F}_s = -k\Delta\vec{x}$$

where:

- $\vec{F}_s$ = spring force (N)
- k = spring constant ($\frac{\text{N}}{\text{m}}$)
- $\Delta\vec{x}$ = displacement of the spring (either extended or compressed) (m)

The negative sign in the equation is because the force is always in the ***opposite direction*** from the displacement, *i.e.,* the force is always back toward the equilibrium position of the object-spring system.

Sample Problem:

Q: A weight of 7 N is hung from a spring, causing the spring to stretch 0.25 m. What is the spring constant for this spring?

A: $\vec{F}_s = -k\Delta\vec{x}$

$$k = \frac{F_s}{\Delta x} = \frac{7}{0.25} = 28\text{ N}$$

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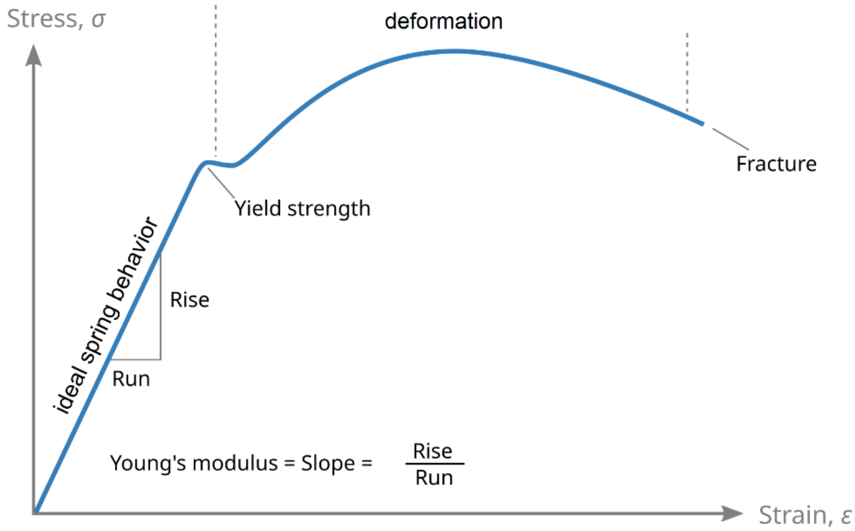
honors (not AP®)

Elastic Limit (Yield Point)

If a spring is stretched beyond its elastic limit (yield point), it deforms (bends irreversibly) and eventually fractures (breaks). The points where these changes happen is shown in a graph of stress *vs.* strain.

stress: the force applied to the spring per unit area of the metal itself.

strain: the amount of proportional deformation (how much the spring expands or compresses)



Young's modulus (Y): the slope of the stress *vs.* strain graph in the linear portion, where the spring behaves as an ideal spring. Named for 19th century British physicist Thomas Young.

The spring constant can be calculated from Young's modulus:

$$k = Y\frac{A}{L}$$

where:

- k = spring constant ($\frac{N}{m}$)
- Y = Young's modulus $\left(\frac{N}{m^2} \equiv Pa\right)$
- A = area (m^2)
- L = length (m)

The linear region of the curve represents the amount of stress and strain under which the spring can be stretched or compressed and will return to its natural shape. If a force greater than the yield strength is applied, the spring will deform (bend) and will no longer return to its natural shape.

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