

TABLE 9–1 Elastic Moduli

Material	Young's Modulus, E (N/m ²)	Shear Modulus, G (N/m ²)	Bulk Modulus, B (N/m ²)
<i>Solids</i>			
Iron, cast	100×10^9	40×10^9	90×10^9
Steel	200×10^9	80×10^9	140×10^9
Brass	100×10^9	35×10^9	80×10^9
Aluminum	70×10^9	25×10^9	70×10^9
Concrete	20×10^9		
Brick	14×10^9		
Marble	50×10^9		70×10^9
Granite	45×10^9		45×10^9
Wood (pine) (parallel to grain)	10×10^9		
(perpendicular to grain)	1×10^9		
Nylon	5×10^9		
Bone (limb)	15×10^9	80×10^9	
<i>Liquids</i>			
Water			2.0×10^9
Alcohol (ethyl)			1.0×10^9
Mercury			2.5×10^9
<i>Gases</i> [†]			
Air, H ₂ , He, CO ₂			1.01×10^5

[†] At normal atmospheric pressure; no variation in temperature during process.

If we compare rods made of the same material but of different lengths and cross-sectional areas, it is found that for the same applied force, the amount of stretch (again assumed small compared to the total length) is proportional to the original length and inversely proportional to the cross-sectional area. That is, the longer the object, the more it elongates for a given force; and the thicker it is, the less it elongates. These findings can be combined with Eq. 9–3 to yield

$$\Delta L = \frac{1}{E} \frac{F}{A} L_0, \quad (9-4)$$

where L_0 is the original length of the object, A is the cross-sectional area, and ΔL is the change in length due to the applied force F . E is a constant of proportionality[‡] known as the **elastic modulus**, or **Young's modulus**; its value depends only on the material. The value of Young's modulus for various materials is given in Table 9–1 (the shear modulus and bulk modulus in this Table are discussed later in this Section). Because E is a property only of the material and is independent of the object's size or shape, Eq. 9–4 is far more useful for practical calculation than Eq. 9–3.

EXAMPLE 9–10 Tension in piano wire. A 1.60-m-long steel piano wire has a diameter of 0.20 cm. How great is the tension in the wire if it stretches 0.25 cm when tightened?

APPROACH We assume Hooke's law holds, and use it in the form of Eq. 9–4, finding E for steel in Table 9–1.

SOLUTION We solve for F in Eq. 9–4 and note that the area of the wire is $A = \pi r^2 = (3.14)(0.0010 \text{ m})^2 = 3.14 \times 10^{-6} \text{ m}^2$. Then

$$F = E \frac{\Delta L}{L_0} A = (2.0 \times 10^{11} \text{ N/m}^2) \left(\frac{0.0025 \text{ m}}{1.60 \text{ m}} \right) (3.14 \times 10^{-6} \text{ m}^2) = 980 \text{ N}.$$

The large tension in all the wires in a piano must be supported by a strong frame.

[‡]The fact that E is in the denominator, so $1/E$ is the actual proportionality constant, is merely a convention. When we rewrite Eq. 9–4 to get Eq. 9–5, E is found in the numerator.