

## February 16: Noether's Theorem and Atoms

### Objectives

- Relate continuous symmetries to conservation laws.
- Describe the behavior of molecules in solids, liquids, and gases.

### What's the Point?

- Conservation laws reveal the structure of the universe!
- What are solids, liquids, and gases?

### Noether's Theorem

Emmy Noether (1882–1935) showed that when physical laws are unchanged after a continuous transformation, a physical quantity related to the transformation is conserved. This establishes the correspondence between three deep symmetries and three important conserved quantities.

Deep symmetry: the laws of physics do not change with	Quantity conserved
<b>time</b>	<b>energy</b>
<b>position</b>	<b>momentum</b>
<b>orientation</b>	<b>angular momentum</b>

### Atoms

“...all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.” R.P. Feynman, *The Feynman Lectures on Physics*, vol.1. The behavior of atoms is responsible for most of the properties of matter that we will study in this course.

Sometimes it makes more sense to refer to **molecules**, which can be individual atoms or groups of atoms tightly connected.

### Liquids

Molecules of **liquids** are in close contact, constantly moving past each other. Liquids are relatively difficult to compress.

### Gases

Molecules of **gases** are separated by great distances, and seldom interact with each other. Gas molecules exert pressure on their surroundings by collisions. Collisions are more frequent if the gas is compressed, the number of molecules increases, or the kinetic energy (temperature) of the molecules increases.

Compared to liquids and solids, gases are relatively easy to compress.

## **Solids**

Molecules of **solids** vibrate about fixed positions. They resist being pushed closer together or pulled farther apart.

## **Phase changes**

Molecules gain kinetic energy going from gas to liquid or from liquid to solid, and lose kinetic energy going the other way. This is because of the lower potential energy per molecule in solids than liquids than gases.