For flame is par excellence Fire: but flame is burning smoke, and smoke consists of Air and Earth.

—ARISTOTLE, 350 B.C., BOOK 2, PART 4

Things fall apart, the center cannot hold.

—WILLIAM BUTLER YEATS, 1921

What Is Fire?

Though a familiar presence throughout our lives, the essence of burning still seems mysterious. What is happening as flames quietly crackle or, sometimes, roar with the powerful voice of energy unleashed? What is this thing called "fire"?

To Aristotle and other ancient Greeks, fire was an agent that imposed forms on the remaining fundamental elements: earth, air, and water. Though we no longer think of fire as an "element," the idea that it is a transforming agent is very familiar to modern fire ecologists. Fire on the California landscape has shaped evolutionary adaptations of both plants and animals.

Combustion, another name for fire, is an energy-releasing chemical reaction that, once initiated, can become self-perpetuating. When enough heat is generated to make the fire "contagious," nearby fuels are dried and their temperature increases. At the ignition temperature, chemical bonds between carbon and hydrogen break. It is vaporized molecules, rather than the solid fuel, that actually ignite in flaming combustion as the gaseous fuel cloud reacts with oxygen in the air. That oxidation (yet another name for burning) produces carbon dioxide and water.

Much slower oxidation burns within the cells of plants and animals, whose aerobic metabolisms break down food for cellular energy. Rusting metal is yet another example of oxidation occurring too slowly to give off noticeable heat.

The heat generated as wildlands burn reveals how much sunlight energy was captured and stored by plants during photosynthesis. Though the maximum potential yield is never achieved (because wildfires do not produce complete combustion), and significant energy always goes toward evaporation of water, phenomenal heat releases still occur. Flames that tower 100 feet into the sky visually suggest that scale (pl. 2). In wildfires with just 12-foot flame lengths, every yard along

Plate 2. A wall of flame burns through desert shrubs and Joshua trees as a California Department of Forestry and Fire Protection truck monitors the Sawtooth Complex wildfire of 2006.

the leading edge of the fire may generate 4,000 kilowatts of heat energy, the equivalent of 4,000 single-bar electric heaters stacked on top of each other. A domestic example is revealing: the energy in one cord of dry firewood can equal that in 160 gallons of gasoline (a stacked cord is four feet wide, eight feet long, and four feet high).

Fire is one way that vegetation energy and molecular complexity succumb to the second law of thermodynamics. According to that law of physics, energy tends to disperse from where it is concentrated, and randomness, ultimately, increases. Since fire breaks complex molecules down to simpler forms, it is a type of decomposition, releasing and recycling nutrients. In fact, in dry climates like those found across much of California, fire has been the primary agent of decomposition.

Flames are the visible evidence of fire (pl. 3). Their glowing light comes from particles of soot—unburned carbon—heated to incandescence. The particular colors that are radiated depend on temperature. In most wildland fires, yellow and orange predominate, with more red appearing as the fire cools. White and blue flames are hottest but more often are seen outside wildland settings in fires stoked with bellows or when flammable liquids burn. A pattern of colors corresponding to energy levels is similarly apparent in rainbows, which reveal the spectrum of energy levels in white light: lowest-energy bands are red, and energy increases through progressive color bands toward the blue and violet ranges.

Plate 3. A flame is the visible evidence of fire.

Smoke commonly appears with flames because combustion is never complete. Soot rising away from the hottest parts of the fire in heated air is visible as black smoke. Smoke (pl. 4) that is whiter includes steaming water evaporated from the fuel.

Plate 4. Different colors of smoke reflect different moisture levels and types of burning fuels.

Plate 5. Ash builds up as a fire smolders, because combustion is never completely efficient.

The gaseous flaming phase eventually collapses back onto solid fuel, and then heat can continue gnawing away at a log as glowing combustion. Ash residues (pl. 5) of noncombustible materials, such as silica, are another sign that the burning process is never completely efficient. Ashes can pile up and smother fires, putting them out if they block access to oxygen. So, we stir campfires as they burn down and must regularly clean ashes from fireplaces and woodstoves.

The Fire Triangle

The basic requirements for fire are often summarized as a triangle whose three sides are oxygen, fuel, and heat (fig. 1). Firefighters are taught to put out fires by eliminating any one of the triangle's sides. They can shovel dirt onto flames to smother them, depriving them of oxygen, for example. Often they will scrape a line down to bare soil around a fire to deprive it of new fuel. Or, they might use water to cool a fire down below its ignition temperature.

Oxygen: Fire Breath

Though the predominant gas in Earth's atmosphere is nitrogen, the 21 percent that is oxygen gas is key in processes that cycle energy. The oxygen molecule is very reactive. Not content to stay in that O_2 form, it is always ready to react chemically with other molecules it encounters. That reaction is called oxidation.

Scientist James Lovelock has speculated that oxygen concentrations above 25 percent would make *everything* flammable, even damp wood; but if the level fell below 15 percent, not even the driest twigs would burn. If oxygen levels were

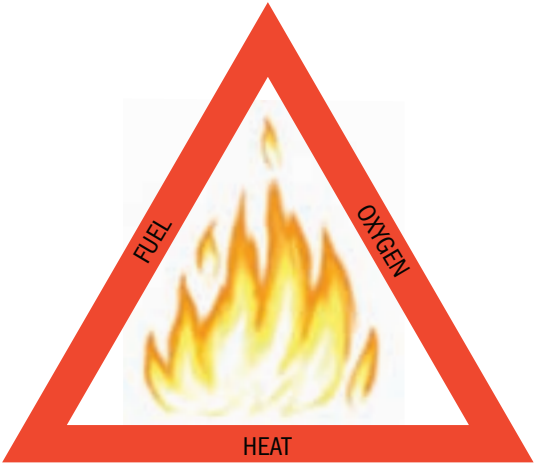

Figure 1. The fire triangle: fires require heat to work on fuel in the presence of oxygen.