Project-II Team Gamma

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[Introduction]

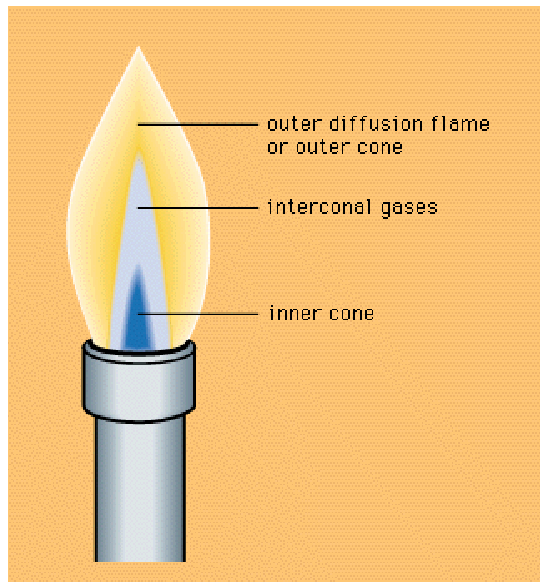
"Discovery of fire was a start to civilization of the human". The picture below with three different fire phenomena is telling the story of fire and human beings. In Greek stories, fire is brought by Prometheus and hence gives the knowledge and benefits to humans. However, fire is forbidden from god Jupiter and then bring done the Pandora 's Box to the earth with disease and misfortune inside it. In the right side of picture, these scary claws make people have un-secure feelings and show the power of fire to destroy things. In the left side of picture, flames like dancing spirits present the inspirations of fire and appreciation of human beings. In the middle, a rocket or missile launching is either evil or god depending on how humans utilize it. The turbulent and mixing colors of left and right shows the beauty of nature and the layered color in the middle demonstrates the endless desires to pursue controlling the universe by human beings.

[Flame Physics]

Fire flames produce light from a mixture of atomic and molecular de-excitation, and the heating of soot particles. The soot particles are so small that they have quantized vibration states, so they do not radiate as efficiently as "blackbodies" [1].

The principal quantitative characteristic of a flame is its normal, or fundamental, burning velocity, which depends on the chemical and thermodynamic properties of the mixture, and on pressure and temperature, under given conditions of heat loss. The burning velocity value ranges from several centimeters even to tens of meters, per second. The dependence of the burning velocity on molecular structure, which is responsible for fuel reactivity, is known for a great many fuel–air mixtures. [2]

When a premixed flame burns in open air with an excess of fuel, there appears in addition to the flame zone a zone of diffusion flame; this is accounted for by the diffusion of atmospheric oxygen, as, for example in figure-2 [2], in the Bunsen flame produced by a burner to which the air intake can be regulated, thereby altering the flow from an intensely hot one—in which most of the fuel gases are oxidized to carbon dioxide and water—to a relatively low temperature flux, in which most of the fuel gas is only partially oxidized. Such flames consist of an inner and outer cone—two zones in which different chemical reactions take place, the reducing and oxidizing zones, respectively. The oxidizing nature of the outer cone is due to excess oxygen.



A widely applied thermal theory, one of the first flame propagation theories, implies that combustion proceeds primarily at temperatures close to the maximum the flame can achieve. Flame propagation is accounted for by heat energy transport from the combustion zone to the unburned mixture, to raise the temperature of the mixture. Diffusion theory assumes that thermodynamic equilibrium sets in behind the flame front at a maximum temperature, and that radicals produced in this zone diffuse into the unburned mixture and ignite it. Both heat transport and diffusion of active particles must be considered essential for ignition.

An idealized model can be constructed as followed [3] of unburnt and burned gaseous fuel, separated by a thin transitional region of width δ in which the burning occurs. The burning region is commonly referred to as the flame or flame front. In equilibrium, thermal diffusion across the flame front is balanced by the heat supplied by burning

$$\begin{aligned}\frac{\partial(\rho U)}{\partial t} + \nabla\cdot(\rho UU) &= -\nabla\pi + \rho\vec{g} \ ,\\ \frac{\partial(\rho h)}{\partial t} + \nabla\cdot(\rho Uh) &= \nabla\cdot(\lambda\nabla T) - \sum_k \rho q_k \dot{\omega}_k \\ \frac{\partial(\rho X_k)}{\partial t} + \nabla\cdot(\rho UX_k) &= \rho\dot{\omega}_k \ .\end{aligned}$$

where ρ, U, and h are the density, velocity, and enthalpy respectively. The enthalpy is related to the internal energy, e through $h = e+p/\rho$. X_k is the abundance of the kth isotope, with reaction rate $\dot{\omega}_k$ and energy release q_k. T is the temperature and λ is the thermal conductivity. Finally, g is the gravitational acceleration.

[Principles of flame color perceptions]

The light emitters can be grouped into two main categories: solid state emitters (black body radiation) and gas phase emitters (molecules and atoms). A black body is an ideal emitter which is capable of absorbing and emitting all frequencies of radiation uniformly. In the real world, many solids do emit light in the same relative proportions as a black body, but not in the same amounts. The *emissivity* of a solid substance is the factor relating observed and theoretical radiant energy.

Followings give a summary of visual temperature phenomena of solid bodies - for instance, a glowing piece of charcoal, a good approximation to the black body. [4]

T, K	oC	Subjective colour
750	480	faint red glow
850	580	dark red
1000	730	bright red, slightly orange
1200	930	bright orange
1400	1100	pale yellowish orange
1600	1300	yellowish white
>1700	>1400	white (yellowish if seen from a distance)

In principle, we could generate blue light with a hypothetical black or grey body at 9000 K and up, which is the temperature of blue stars. However, it is not practical. We need specific emitters of colored light.

The followings[4] summarize the sources of colored light used in today's fireworks.

Color	**Emitters used**	**Wavelength range**
Yellow	Sodium D-line atomic emission	589 nm
Orange	CaCl, molecular bands	several bands, 591-599 nm, 603-608 nm being the most intense
Red	SrCl, molecular bands	a: 617-623 nm b: 627-635 nm

		c: 640-646 nm
Red	SrOH(?), molecular bands	600-613 nm
Green	BaCl, molecular bands	a: 511-515 nm b: 524-528 nm d: 530-533 nm
Blue	CuCl, molecular bands	403-456 nm, several intense bands, less intense bands between 460~530 nm

[Camera setup]
Three different photos are shoot by Nikon D80 and Photoshop overlapped to present the picture above.

1. Fire claw (right hand side): Fire on iso-propane on the ground
Image Size: Large (3872 x 2592)
Lens: 18-135mm F/3.5-5.6 G
Focal Length: 80mm
1/1250 sec - F/5.6 - ISO 1600
2. Dancing spirits in fires (left hand side): Fire on oven with grill dipped in Zinc solution
Image Size: Large (3872 x 2592)
Focal Length: 38mm
1/40 sec - F/4.5 - ISO 1600
3. Rocket launching (middle): M.A.P.P. gas gun firing toward the ground
Image Size: Large (3872 x 2592)
Focal Length: 135mm
1/15 sec - F/10 - ISO 1600

[Summary]
One of the greatest discoveries made by man alone on this good earth is the art of making and maintaining fire. During the pursuit of knowledge and control of fires, it is managed to help with benefits of human beings or endanger other's life. As a scientist or engineers, we shall keep thinking and pursuing the knowledge and beauties brought from it and also bear in mind to keep it in the right direction and path.

[Reference]
[1] http://www.physics.utoledo.edu/~lsa/_color/06a_flames.htm
[2] http://www.britannica.com/eb/article-49313/oxidation-reduction-reaction
[3] Journal of Physics: Conference Series **16** (2005) 405–409
[4] http://cc.oulu.fi/~kempmp/colours.html