Two-Part Presentation

1. Michael Faraday –
   Scientist - Researcher
   Lecturer - Inventor

2. The Chemical History
   of a Candle --
   The Lectures
   The Experiments
   The Teachings &
   Learnings
Information Sources

- Michael Faraday – *The Chemical History of a Candle*
  2002 (Dover, Mineola, NY)
- J.G. Crowther - *Men of Science*
  1936 (W.W. Norton & Co., NY, NY)
- The Internet; Wikipedia

Michael Faraday (1791-1867): Monumental Scientist

- J.G. Crowther called Faraday
  “The greatest physicist of the 19th century & the greatest of all experimental investigators of physical nature.”
- Albert Einstein recognized Faraday’s importance by comparing his place in scientific history to that of Galileo
- Einstein kept a photograph of Faraday alongside a painting of Sir Isaac Newton in his study
Faraday: a Prolific Reader & Writer

• Born poor, Faraday adapted well to living by simple means & developed a strong work ethic
• Completed 7 yr apprenticeship as a bookbinder & bookseller
• Apprenticeship afforded opportunity to read extensively, especially books on science
• In 1812 (20 yr old) Faraday attended lectures by Sir Humphrey Davy at Royal Institution
• Faraday later sent Davy 300-page book (!) based on notes taken during the lectures

Sir Humphrey Davy:
Faraday’s Mentor at Royal Institution

• After receiving Faraday’s book of notes, Davy damaged his eyesight in a lab accident
• Davy sought out & employed Faraday as his secretary
• Eventually Davy appointed Faraday to his Chemical Assistant position, Mar-1813
• With the support of his mentor, Sir Humphrey Davy, Faraday advanced his scientific prowess & ultimately achieved his lofty position
Faraday, Strong Voice for Science

- Davy impressed upon Faraday an important concept – to highlight science as a necessity for societal development
- Faraday introduced key scientific principles to fellow scientists & society, at large through
  + brilliant research
  + entertaining experiments &
  + easy to understand lectures
- In essence, Faraday became the voice of science for the mid-third of the 19th century

Faraday: The Lecturer

- As his scientific prowess developed, Faraday began to study the art of lecturing
- He trained in this endeavor much as an athlete trains today
- Faraday believed his audiences “expect to be entertained not only by the lecture, but by the manner of the lecturer . . .”
- He believed that listeners deserved reason, sense & a level of respect from the lecturer
Michael Faraday – Major Professional Accomplishments

- 1824 - Elected member of Royal Society (33 yr old)
- 1825 - Appointed Royal Institution Directory of the Laboratory
- 1835 - Appointed for life as 1st Fullerian Professor, Royal Institution of Great Britain without obligation to lecture (44 yr old) -- but he lectured anyway throughout his career

Michael Faraday portrait by Thomas Phillips, c 1841-42

Michael Faraday – Major Scientific Accomplishments

- Key discoveries in fields of electromagnetism & electrochemistry
  + Faraday’s disk was the first generator (electromagnetic rotary device)
  + Formed the foundation for today’s electric motor & power generation technology
Faraday’s Law of Induction

- Faraday’s law describes relative movement of a circuit & a magnetic field - the phenomenon on which electrical generators are based
- When a magnet is moved relative to a conductor, or vice versa, an electromotive force (EMF) is created
- If the system is connected through an electrical circuit, current will flow - thus mechanical energy of motion is converted to electrical energy

Michael Faraday – Other Scientific Accomplishments

- Discovered the compound benzene
- Invented an early form of the classic laboratory “bunsen” burner – for a balanced, clean-burning flame
- With Great Britian’s strong maritime interests, Faraday conducted extensive research on
  + Construction & Operation of Light Houses
  + Corrosion Protection for Ships’ Hulls
Michael Faraday –
Scientific Legacy Key to 1902 Nobel Prize

• Faraday experimented with & discovered the rotational impact of an electromagnetic field on polarized light

• Pieter Zeeman, Amsterdam Univ, improved Faraday’s apparatus to study this phenomenon & received the 1902 Nobel Prize in Physics

• Professor Zeeman enthusiastically referred to Faraday’s work in both his scientific publications & his Nobel acceptance speech

Michael Faraday –
Scientific Legacy Key to 1902 Nobel Prize

• Pieter Zeeman, age 37, was honored along with his mentor, Hendrik Lorentz

• The Zeeman Effect, discovered in 1896, identified the existence of negatively charged electrons & oscillating particles in light from flames

• Research by Faraday & Zeeman opened the door for the next two generations of scientists to study & understand atomic structure
Michael Faraday –
Honors, Accepted or Not

- Rejected Knighthood
- Twice refused election as President of the Royal Society
- Granted retirement home at Hampton Court – now called Faraday House
- Declined Westminster Abbey burial, but is honored with a memorial plaque located near Sir Isaac Newton’s tomb

Faraday Statue, Savoy Place, Inst. of Eng. & Technology

Michael Faraday –
The Chemical History of a Candle

- In 1860 (age 69) Faraday created a series of lectures on chemistry & physics of flames
- Youthful audience introduced to a number of key scientific principles, laws of nature, based on actions of a burning candle
- These Juvenile Auditory lectures are still given each year at the Royal Institution
- Between 1827 & 1860, Faraday gave these Christmas lectures a record 19 times
Faraday's Candle Lectures & Experiments Recreated in 2004-2005

- Ian Russell is a scientist well-known for creating demonstration experiments.
- He presented a ‘Friday Evening Discourse’ to members of the Royal Institution in November 2005, based on Faraday’s candle lectures.
- Russell was honored to stand where Faraday stood when giving his famous Chemistry of a Candle lectures 145 yrs earlier.

Faraday’s Lecture Hall: 1855 & Today

Thanks to Andrew Leach, Member, Royal Institution.
I. Candle: The Flame, Its Sources, Structure, Mobility, Brightness

• “There is not a law [of nature] under which any part of this universe is governed which does not come into play and is touched upon in these phenomena [of the burning of a candle].”

Candle Fuels, Wick & Process of Manufacture Introduced

• Suitable fuels - stearin, sperm oil, beeswax & paraffine
• Wick material typically of cotton or paper
• Molded, dipped or poured methods used for manufacture
Good & Bad Candles; 
Stable vs. Unstable Burn Environments

- Emphasized the need to balance flame heat (size) with wick & candle design
- Discussed the requirements for stable air currents & a horizontal fuel pool in the “cup”
- Excessive fuel delivery, guttering, unstable air currents all create poor candle performance
- Proper design & stable burn environment key to proper candle combustion for light & heat

Concept of Capillary Attraction
Introduced & Demonstrated

- Liquid wax pools in “Faraday’s cup” formed by cooler, solid sides of the candle
- Liquid fuel drawn by “capillary attraction” up wick to burning flame front
- Faraday demonstrated with a colored liquid drawn up a column of salt
Candle Flame Contains Solid Particulates

- Candle flame casts a shadow, proving that solid particulates make up portion of the flame structure
- Faraday demonstrated that direct combustion of carbon particulates produces the candle’s light

II. Brightness of the Flame: Air Necessary for Combustion, Production of Water

- “... I have to ask ... where, after all, the whole candle goes to; because ... a candle being ... burned, disappears, if burned properly ... and this is a very curious circumstance.”
Fresh Air with Sufficient Oxygen Required for Candle Flame to Burn

- Classic experiment - cover a burning candle with glass bell jar causes vapor & condensate to form & candle flame to eventually go out

Candle’s Light Created by Hot Carbon Particles in Center of Flame

- Center of candle flame is cooler & contains combustible matter (Faraday described this as the dark part of the flame's shadow)
- Hot, glowing incandescent carbon particles in flame center create a candle’s luminous light
Candle Luminosity Emanates from Combustion of Solid Carbon Particles

- Faraday demonstrated powder combustion with both gunpowder & lycopodium to illustrate formation of bright light
- Ian Russell’s 2004-05 demonstrations used fine corn flour (photo on right)

Carbon Particles Burn at Flame’s Edge Where Air Contact is Made

- Oxygen-rich lower flame & edges create most heat
- Upper flame is oxygen starved causing incomplete combustion & glowing carbon particles
- With sufficient air contact, all particles can be completely combusted
Faraday’s Wonderful Comment on Carbon Particle Luminosity in the Flame

- “You would hardly think that all those substances which fly about London, in the form of soots & blacks, are the very beauty & life of the flame, . . .”

III. Products from Combustion: Water from Oxygen & Hydrogen

- Experiments demonstrate that water vapor is a key product of candle combustion
Sources of Oxygen & Hydrogen

• More complex experiments show that, water (H₂O) is formed by chemical action of combustion between
  + air - source of element oxygen &
  + some portion of the candle that produces the element hydrogen

• Faraday demonstrated that hydrogen is part of a candle composition, but did not elaborate on its source as the hydrocarbons in the solid fuel

IV. Hydrogen in the Candle

Burns with Oxygen into Water

• One key experiment involved electrolysis of water, using a simple voltaic battery, into one (1) part oxygen & two (2) parts hydrogen

• Burning these two gases, of course, produced water, H₂O, the same product as from a burning candle

• A second experiment showed the effect of pure oxygen vs. air on a candle flame –
  – more rapid & vigorous combustion
  – much brighter light
To Summarize Faraday on the Key Role of Oxygen in Burning a Candle

• When certain things necessary to the combustion of a candle are absent [eg., oxygen], very bad results are accordingly produced

• Good results occur when a candle is burned in a “pure & proper state of air”

V. Oxygen in Air; Nature of the Atmosphere; Carbon Dioxide

• Faraday introduces the concept that air contains other components besides oxygen

• He reminds his youthful audience, based on previous experiments, that an atmosphere of pure oxygen would promote uncontrolled combustion & “all would be burnt rapidly”
Nitrogen is a Key Component of Air

- Oxygen comprises only about 20% of the atmosphere
- Faraday tells his audience that nitrogen, an inert gas, makes up about 80% of the atmosphere, thus diluting the oxygen content to “perform a great and glorious purpose of good to man . . .”

Carbon Dioxide – The Major Product from a Candle Flame

- Production of carbon dioxide, CO₂, from a burning candle flame demonstrated
  
  + Called by Faraday “carbonic acid”

- Classic experiment – pouring a container of carbon dioxide into a cylinder containing a burning candle

\[ \text{CO}_2 \]
Carbon Dioxide Properties Demonstrated

- Experimental results showed carbon dioxide
  - Does not support combustion (candle flame extinguished) &
  - Is heavier than air
- In Lecture V, Faraday completed his demonstrations to illustrate and explain all the components, reactions & products of a burning candle

VI. Carbon: Coal Gas, Respiration & its Analogy to the Burning of a Candle

- “In every one of us there is a living process of combustion going on very similar to that of a burning candle, and I must try to make that plain to you.”
How Similar the Human Body & a Candle Flame!

• In his Final Lecture, Faraday draws the analogy for his youthful audience that like a candle flame, the human body
  + takes in air (oxygen)
  + combusts (or reacts) carbon with oxygen to produce energy &
  + expels carbon dioxide & water as by-products

The Amazing Amount of Carbon Dioxide Generated

• A typical person converts 7 ounces of carbon per day to supply energy needed for the body to function, work, play & stay warm
• 7 oz (200 g) of carbon generate 1.6 pounds (0.73 kg) of carbon dioxide, every day
• We attendees will produce about 2,500 lbs (1,140 kg) of CO₂ during this Candle Congress
• Each pound (0.45 kg) of candle fuel produces 2.3 lbs (1.1 kg) of CO₂ when burned
And where does all this carbon go?

- In a very environmentally focused manner, Faraday informs his audience that “. . . All the plants growing upon the surface of the earth . . . absorb carbon [as carbon dioxide] . . . [thus] growing and prospering.”

Faraday – The Teacher’s Final Quote

- Michael Faraday’s remarks at the end of his lecture series are worth quoting -

  “Indeed, all I can say to you . . . is to express a wish that you may . . . be fit to compare to a candle: that you may, like it, shine as lights to those about you; that, in all your actions, you may justify the beauty of the taper by making your deeds honorable & effectual in the discharge of your duty to your fellow-men.”
In Conclusion

- Based on his informative lectures, entertaining experiments & profound quotes, one could be tempted to conclude that, just maybe, Michael Faraday, 150 years ago, pre-supposed the theme of this 3rd World Candle Congress –
  “Enlightening the World”

Acknowledgements to:

- former Employer, ExxonMobil
- former ExxonMobil Wax Team Colleagues
- former Candle Customers who, collectively, taught me about this fascinating business
- Friends & Associates in the NCA, ALAFAVE & in Europe
Acknowledgements to:

• Friends & current Employers, Bill & Penni Heritage of Heritage Vineyards of Richwood, NJ
• Sherry, my lovely & loving Wife of 39 years
• And to you, my patient & attentive audience

Thank you!