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# The Chemist

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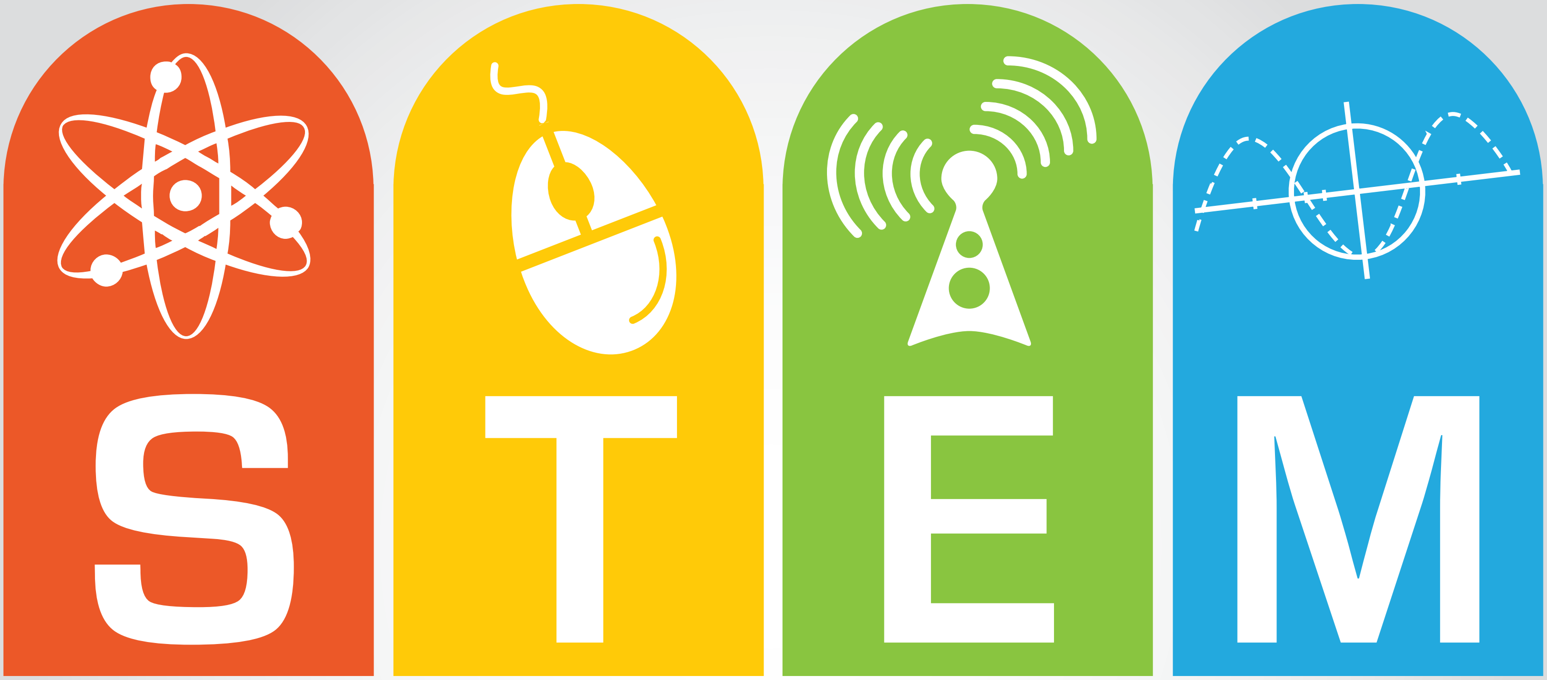

SCIENCE • TECHNOLOGY • ENGINEERING • MATHEMATICS

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- Preparation of Zinc and Calcium Silicate Modified Fly Ash/Styrene Butadiene Rubber Composites
- Ozone in the Stratosphere: An Environmental Accumulation and Flow
- Undergraduate Research Engagement Among STEM Majors
- Discovering Infinite Number of Independent Balanced Forms of Some Typical Chemical Equations

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# The Chemist

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The Chemist (Established in 1923)

# Editorial

## STEM Research, Education and Workforce

**David Devraj Kumar**
*Florida Atlantic University*

Calls for improving Science, Technology, Engineering and Mathematics (STEM) research and education with a goal for increasing STEM workforce, are heard from all segments of society. Scientific associations, such as the Council of Scientific Society Presidents, insist the need for more public dollars for research and development. Business entities demand a stronger STEM workforce. Parents, and society in general, ask for better STEM education in our schools and colleges. While no one is certain how to address these calls, there is consensus that STEM reform is critical to the survival of a nation's economy, prosperity, infrastructure and defense. The lineup of articles in this issue of *The Chemist* samples STEM research, education and workforce.

M. T. Ramesan and co-authors, report a research on surface modified fly ash (styrene butadiene) rubber composites as reinforcing fillers based on the cure, morphology and crystalline nature, thermal, flame and mechanical properties. Fly ash is a waste from thermal power stations and an environmental pollutant. Recent research sheds light on innovative ways of utilizing fly ash for applications in polymer composites, thus reducing their environmental impact. Ronald Persin presents an interesting approach to derive a set of differential equations contributing to the understanding of the formation of ozone layers in the stratosphere. While Susan Losh and Brandon Nzekwe examine how aspects of researcher identity and attitudes of STEM majors affect their awareness of university research opportunities, interest and involvement, Pramode Ranjan Bhattacharjee reports a novel algebraic approach to discovering infinite number of independent balanced forms of chemical equations. "The STEM Workforce" article reprinted with permission from the Department for Professional Employees of AFL-CIO is a fact sheet that presents an occupational overview of STEM. Margot Hall reviews the book *Clinical Toxicology: Principles and Mechanisms* (2nd Edition).

The voluntary efforts of *The Chemist* reviewers who provided feedback are thankfully acknowledged. Thanks to Wade Berstler of Florida Atlantic University for serving as ad hoc editorial assistant on various tasks associated with editing this issue of *The Chemist*, and to Florida Atlantic University for serving as a home base for the editing of *The Chemist*, and enabling the re-establishment of this refereed scientific periodical.

Thank you.

**The Chemist**
Journal of the American Institute of Chemists

# Preparation of Zinc and Calcium Silicate Modified Fly Ash/Styrene Butadiene Rubber Composites

**M.T Ramesan*, V.C. Jasna, Joseph Francis, Abdu Raheem V. P. and Subburaj M.**
*Department of Chemistry - University of Calicut | Kerala, India*
*(*Email: mtramesan@uoc.ac.in)*

**Abstract:** The present work is focused on the effect of surface modified fly ash as reinforcing filler on the cure, morphology and crystalline nature, thermal, flame and mechanical properties of styrene butadiene rubber (SBR) composites. The surface modification of fly ash was monitored by FTIR and XRD studies. The processing characteristics such as cure and scorch time of SBR decreases with increase in concentration of fly ash, but show an enhancement in maximum torque up to 30 parts per hundred rubber (phr) of filler. The dispersion of fly ash in the polymer was analyzed by SEM and XRD. Mechanical properties such as tensile strength, modulus, tear resistance, hardness and heat build-up of the vulcanizate increases whereas the resilience and elongation at break decreases with loading of fillers. Chemically modified fly ash imparts higher mechanical properties than unmodified fly ash/SBR composites. The thermal and flame resistance of the composite increases with increase in concentration of fillers.

**Key Words:** SBR, modified fly ash, mechanical properties, thermal stability, flame retardancy.

## INTRODUCTION

Particulate filled polymer composites are becoming attractive because of their wide applications and low cost. Reinforcement of elastomeric compounds enhances mechanical properties by the addition of inorganic fillers, which is one of the most important phenomena in material science and technology. Incorporating inorganic mineral fillers into elastomers improves various physical properties of the materials, such as mechanical strength, modulus, hardness, etc. In general the mechanical properties of particulate filled polymer composites depend strongly on size, shape and distribution of filler particles in the polymer matrix and extent of interfacial bonding between the filler and matrix [1-3]. Studies of mineral fillers such as talc, kaolin, mica and calcium carbonate are relatively well known to enhance the stiffness and strength of filled rubber. Of more than 100 different types of inorganic/organic reinforcing materials researched and reported in the literature, only a few fillers like carbon black and silica have been commercialized and used extensively [4].

Fly ash (FA) is a waste mineral product of thermal power stations. Environmental problems due to fly ash is a major concern. There are many conventional ways for using the waste fly ash in construction and agricultural sectors to reduce environmental pollution [5]. However, the utilization of fly ash is very low percentage, the remainder being disposed of in landfills, possibly causing serious environmental problems [6,7]. Recently, new ways of utilizing fly ash have been explored to protect the environment and provide useful ways for its disposal.

Styrene butadiene rubber (SBR) find important application in many industries related to tire, hose, cable, health care products, and so on, owing to their excellent abrasion resistance and elastic nature. However, SBR has poor tensile strength and flammability, so great care must be taken in selecting an appropriate elastomer for various applications that required performance and durability. The strength and flame resistance of SBR can be improved by the addition of fly ash particles. A significant problem in fly ash filled system is caused by the poor adhesion and the non-uniform dispersion of filler in the polymer matrix. Surface modification of fly ash by suitable methods can overcome these problems by enhancing surface interactions between the polymer and inorganic fillers. The main objectives of the work are, (1) to prepare zinc and calcium silicate groups on the surface of waste fly ash particles, (2) to prepare modified and unmodified fly ash incorporated SBR composite, (3) to study the processability and mechanical properties of the fabricated polymer composite and (4) to analyze the effect of loading of zinc and calcium silicate modified fly ash on the thermal stability and flame retarding behavior of SBR composites.

## EXPERIMENTAL

### Materials

Fly ash (FA) (Composition: 63 wt% $SiO_2$, 30 wt%$Al_2O_3$, 3.5 wt% MgO, 2.5wt% CaO, 1wt% $TiO_2$ and 0.65 wt %$K_2O$; specific gravity (2.08 g/$cm^3$) was obtained from thermal power station, Deepnagar, Bhusaval, Maharashtra, India. SBR -1502 grade was obtained from Synthetics & Chemicals Ltd, U.P., India. ZnO, stearic acid, TDQ, CBS, processing oil, sulfur, $ZnCl_2$, NaOH, $Ca(OH)_2$ were obtained from local chemical suppliers.

### Methods

### Surface Modification of Fly Ash

1. **Preparation of Zinc Silicate Modified Fly Ash**
   Zinc chloride was dissolved in distilled water followed by adding sodium hydroxide solution (1:1 molar ratio) and stirring the mixture for 15 minutes. The precipitated zinc hydroxide is then washed several times with water to remove the byproduct (NaCl) and any un-reacted zinc chloride. Fly ash was then added to the zinc hydroxide precipitate and stirring was continued for 2 hrs at 80$^0$C. The reaction between zinc hydroxide and silanol unit present in fly ash particles leads to the formation of zinc silicate on surface of fly ash.

2. **Calcium Silicate Modification on Zinc Silicate Coated Fly Ash**
   Calcium silicate is coated on the surface of zinc modified fly ash by the addition of calcium hydroxide solution ($Ca(OH)_2$ in 200 ml water ) with a ratio of zinc fly ash / $Ca(OH)_2$ of 5:2 and the resulting slurry was refluxed for 4 hrs at 100$^0$C. The reaction between calcium hydroxide with free silanol group present in the surface of zinc silica modified fly ash leads to the formation of calcium silicate on the surface of fly ash. The zinc silicate and calcium silicate coated fly ash (ZnCa FA) was then dried at 100$^0$C.

3. **Preparation of Modified and Unmodified SBR/Fly Ash Composites**
   Composites were prepared by mixing SBR with different amounts of modified and unmodified fly ash in a two-roll mixing mill with a friction ratio of 1:1.4, as per ASTM D15-627. The basic formulation used in the study is given in Table 1.

**Table 1: Recipe for chemically modified and unmodified fly ash filled SBR composites.**

| Ingredients | Parts per hundred rubber (phr) |
|---|---|
| SBR | 100 |
| Stearic acid | 2 |
| Zinc oxide | 5.0 |
| TDQ | 1.0 |
| CBS | 1.8 |
| Processing oil | 1 wt% of fillers |
| Fly ash | 10, 20, 30 and 40 |
| ZnCa silicate modified fly ash | 10, 20, 30 and 40 |
| Sulphur | 2.2 |

### Characterization

Cure characteristics of modified and unmodified fly ash/SBR composites were studied using a Monsanto Rheometer R-100 at 150$^0$C according to ASTM D-2705. The compounds were vulcanized to their respective cure time in a hydraulic press at 150$^0$C and a pressure of 4.4 Pascal. The different physical properties such as tensile strength, tear resistance, hardness, resilience and heat buildup were analyzed, as per the relevant ASTM standard.

## RESULT & DISCUSSION

### FTIR Characterization

FTIR spectra of fly ash and zinc/calcium silicate modified fly ash are shown in Figure 1. It can be seen that the characteristic OH vibration of fly ash appeared at 3516 and 3446 $cm^{-1}$. In the case of zinc and calcium coated fly ash, the OH vibration appeared only at 3523 $cm^{-1}$; this is due to the intermolecular interaction between silanol group of fly ash with the hydroxides of zinc and calcium, which leads to the formation of zinc and calcium silicate on fly ash particles. It is evident from the figure that the characteristic absorption band of the OH bond of modified fly ash is shifted to higher frequencies (i.e., 3516 to 3523 $cm^{-1}$), indicating the chemical modification of fly ash particles. Moreover, the reaction between zinc and calcium hydroxide with silica unit of fly ash produces a new absorption band at 741 $cm^{-1}$, which confirms the formation of zinc and calcium silicate on the surfaces of fly ash particles.

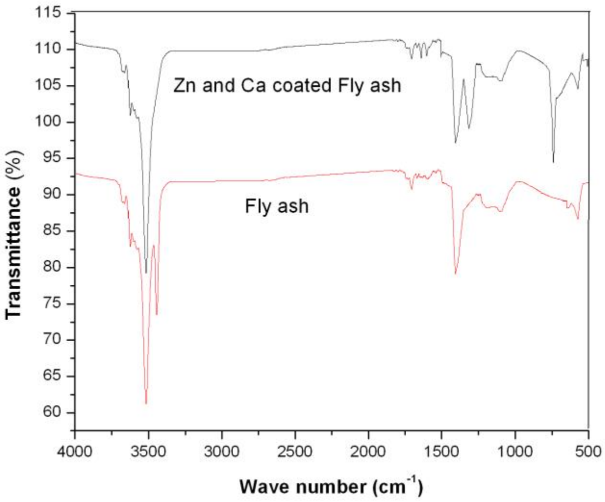

**Fig 1. FTIR spectra of fly ash and zinc and calcium silicate modified fly ash**

### XRD Pattern of Surface Modified Fly Ash Particles

XRD is used to analyze the chemical composition and crystal structure of the prepared fly ash particles. Fly ash modified with zinc and calcium silicate showed various diffraction patterns in the XRD spectra indicating the crystalline nature of the samples (Figure 2). It is observed that chemically modified fly ash shows the diffraction pattern of quartz at $2\theta \sim 40.6^0$, $46.4^0$ and $55.6^0$ along with the mullite XRD peak at $2\theta \sim 30.8^0$ and $35.4^0$ [8]. The characteristic peak of mullite is stronger; whereas, the characteristic peaks of quartz ($SiO_2$) become weaker, which indicate that the modification is mainly taking place on the silanol group present in the surface of fly ash particles. The reaction between hydroxides of zinc and calcium with the silanol or alumina group present on the surface of fly ash particles lead to several silicate and aluminate components such as $Zn_4Si_2O_7(OH)_2.(H_2O)$, $ZnSiO_4$ $Ca_3Si_3O_9.H_20$, $CaAl_2(SiO_3)_4.2H_2O$, $Ca_5Al_6O14$ [9]. These inorganic components that adhere to the surface of fly ash particles affect its surface morphology.

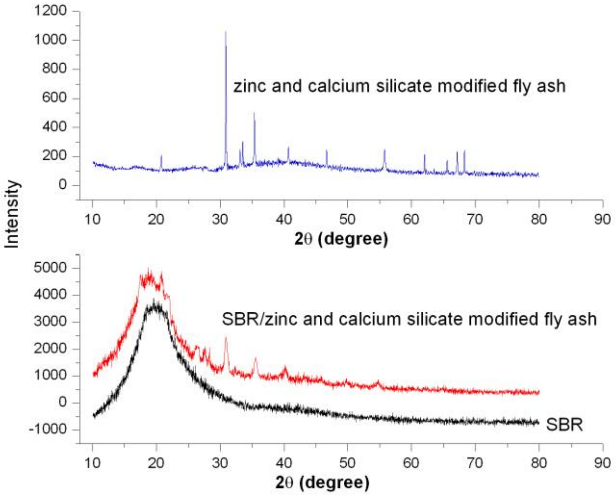

**Fig 2. XRD pattern of chemically modified fly ash, SBR and ZnCa-fly ash filled SBR.**

### XRD Studies of SBR/ZnCa-Fly Ash Composites

The XRD pattern of SBR and SBR with 30 phr of ZnCa-fly ash composite is given in Figure 2. It is observed that pure SBR has a broad diffraction peak at about $2\theta \sim 20^0$, indicating its amorphous nature. However, the XRD pattern of SBR/ZnCa-fly ash composite exhibit few peaks of modified fly ash along with the amorphous peak of SBR. The slight crystalline nature of the composite indicates that filler particles are uniformly distributed into the macromole chain of SBR, which is due to the strong interaction between modified fly ash and the polymer.

### Morphology of SBR/ZnCa-Fly Ash Composites

SEM images of SBR with zinc and calcium silicate coated fly ash are shown in Figure 3. It can be observed that at lower concentration of fillers (10 phr), the fly ash particles are unequally distributed within the polymer matrix. As the concentration of filler increased to 30 phr, the fly ash particles are found to be uniformly dispersed in the polymer with a smooth surface. Modifying fly ash with zinc and calcium hydroxide, leading to the formation of zinc and calcium silicate, is the main reason for getting the uniform morphology. The smooth and spherical structure of fly ash particles after the chemical modification can be helpful in increasing the effective surface area for interacting with the polymer chains. However, as the concentration of fly ash increased to 40 phr, the surface of the composite becomes mottled, indicating the agglomeration of fly ash particles.

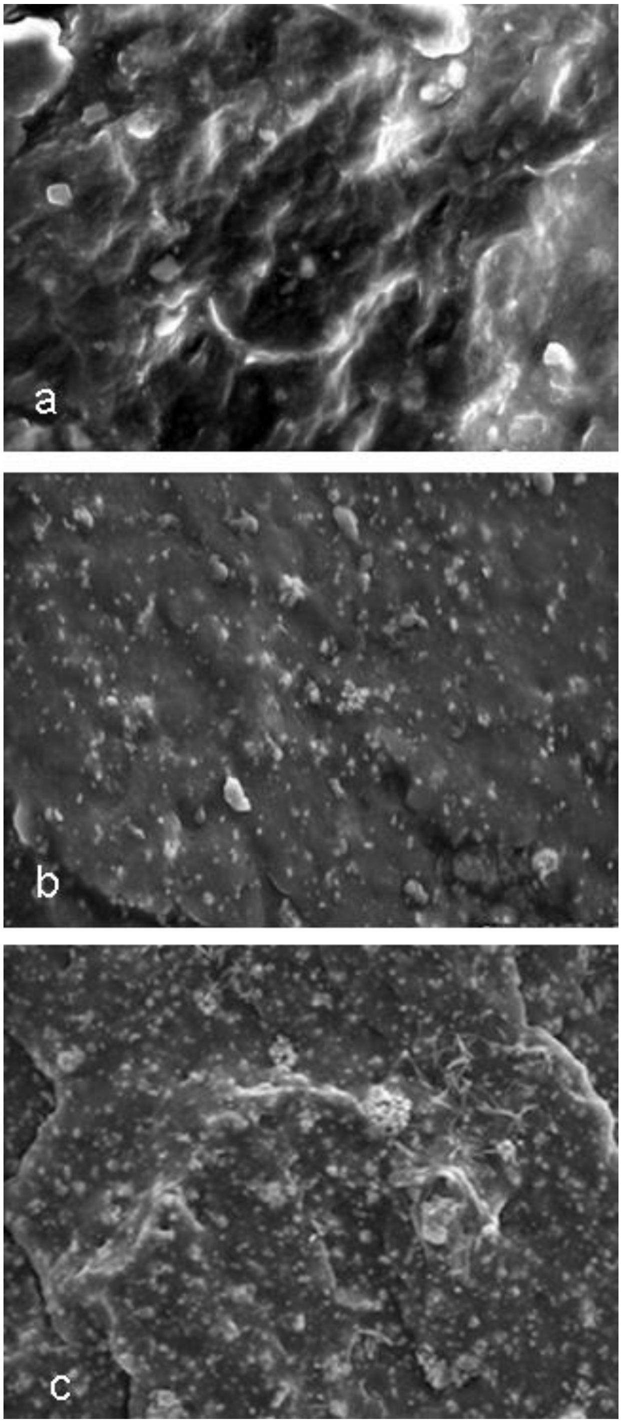

**Fig 3. SEM picture of (a) 10 phr (b) 30 phr (c) 40 phr of ZnCa-fly ash filled SBR.**

### Processing Characteristics of SBR/ZnCa-Fly Ash Composites

The cure characteristic of SBR with various dosages of modified and unmodified fly ash at $150^0$C is given in Table 2. The cure time and scorch time decreases not only with the loading of fillers, but also with the chemical modification of fly ash particles. The reduction in optimum cure time is due to the effect of increased heat conductivity of different metal particles present in fly ash. Moreover, the surface modification in fly ash particles reduces the polarity of the filler particles (silanol group undergoes reaction with zinc and calcium hydroxide), which is responsible for the better processability of modified fly ash/SBR composite. It is also evident from the table that the maximum torque increased with increase in concentration of filler up to 30 phr. This is due to the strong adhesion between the filler and the polymer. The minimum torque value is found to be lower for an unfilled sample, which is due to the poor reinforcement effect of the matrix. It can be inferred that the processability of the composite is further enhanced by the use of chemically modified fly ash particles as compared to unmodified fly ash/SBR composite.

**Table 2: Cure characteristics of modified and unmodified fly ash filled SBR composites.**

| Properties | SBR/ZnCa-flyash (phr) | | | | |
|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 |
| Maximum torque (dNm) | 30 | 32<br>(29)* | 34.5<br>(31.2) | 36.6<br>(34) | 35.5<br>(32.5) |
| Minimum torque (dNm) | 7 | 9<br>(8) | 10<br>(9) | 11.5<br>(10) | 11.7<br>(10) |
| Optimum cure time (min) | 13 | 11<br>(13) | 10<br>(12) | 9<br>(11) | 8<br>(10) |
| Scorch time (min) | 3.0 | 2.75<br>(2.5) | 2.5<br>(2.25) | 2.25<br>(2) | 2.0<br>(1.75) |

*Values in parentheses indicate unmodified fly ash composites

### Mechanical Properties

The influence of fly ash and ZnCa-fly ash on the physical properties of SBR is given in Table 3. The modulus at 200% elongation increases with increasing the loading of fly ash particles up to 30 phr. The strong adhesion between fly ash and SBR is responsible for the modulus enhancement. The tensile strength of the composite increased with the increase in loading of filler up to 30 phr. Further addition of filler results in a slight decrease in mechanical strength, due to the agglomeration of filler particles. As the loading of filler in the polymer increases, elongation at break decreases and the reduction in elongation at break are considered as the criteria for the reinforcement of fillers [10,11]. Like tensile strength, the tear resistance value increases with increase in loading of filler up to 30 phr (Table 3). This means that the more uniform dispersion of filler in SBR is due to the large interfacial area of contact resulting from chemical modification of fly ash particles [12]. Resilience showed a continuous decrease with loading of fillers whereas the hardness increases. Hardness of vulcanizate is usually increased by the addition of reinforcing fillers. Also, the increase in hardness is usually related to the high tensile modulus and the increasing amount of fly ash particles in the polymer matrix. It is also observed from the table that the modified fly ash composite exhibit better mechanical properties than unmodified fly ash filled SBR compounds.

**Table 3: Mechanical properties of FA and ZnCa-fly ash/SBR composites.**

| Properties | Fly ash particles (phr) | | | | |
|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 |
| Tensile strength (MPa) | 2.0 | 2.9 (2.3) * | 3.5 (3) | 5.2 (4) | 5.1 (3.9) |
| Tear strength (kN/m) | 33 | 35 (33) | 39 (37) | 42 (40) | 40 (37) |
| Modulus, 200 % (Mpa) | 1.1 | 2.0 (1.3) | 2.8 (2) | 3.4 (2.5) | 3.1 (2.4) |
| Elongation at break (%) | 430 | 420 (397) | 390 (365) | 380 (350) | 365 (335) |
| Hardness (Shore A) | 32 | 34 (34) | 36 (35) | 39 (38) | 42 (41) |
| Resilience (%) | 39.0 | 37 (36) | 35 (34) | 33 (32) | 31 (30) |
| Heat build-up | 15 | 17 (17) | 20 (19) | 23 (22) | 26 (24) |
| LOI | 16 | 18 | 20.4 | 22.8 | 24.2 |

* Values in parentheses denote unmodified fly ash composites

**Thermogravimetric Analysis (TGA)**

Figure 4 shows the thermogravimetric curves of SBR and SBR with 20 phr and 40 phr of modified fly ash particles. All of the samples undergo single stage decomposition. SBR decomposes at 365$^0$C, while the composite with 20 phr of composite decomposes at 376$^0$C (whereas 40 phr composite decomposes at 385$^0$C). The higher thermal stability of the composites is due to the interaction of fly ash with the macromolecular chain SBR. It can also be seen from the figure that the final residue (char) of SBR is about 10%, compound with 30 phr, exhibit a char residue at 14%. It is already reported that the final char residue resulting after the thermal decomposition is the measure of the flame resistance of a material [13]. The increase in char residue with the modified fly ash particles clearly proves that the flame resistance of the composite increases with the addition of fillers. However, this will be explained more specifically with the help of LOI values.

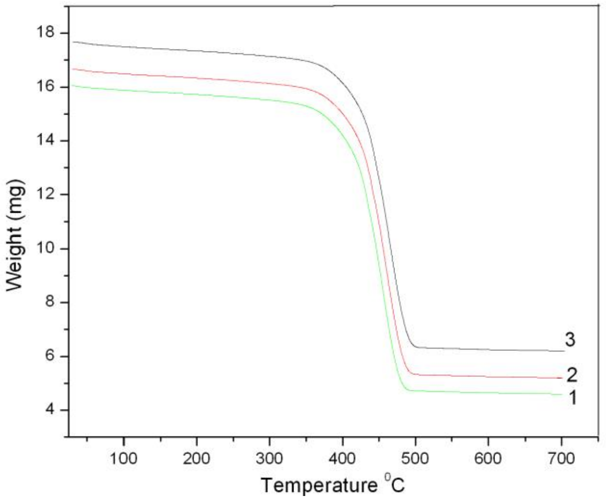

**Fig 4. TGA curve of (1) SBR (2) 20 phr (3) 40 phr fly ash filled SBR.**

**Effect of ZnCa-Fly Ash on the Flame Retardency Behavior**

The limiting oxygen index (LOI) value is expressed as a number indicating the percentage of oxygen needed for the self-combustion of a material. LOI is the direct measure of the flame resistance of a polymeric material. The LOI value of SBR with 0, 10, 20, 30, 40 phr of zinc and calcium coated fly ash composites are given in Table 3. It is clear from the table that the flame resistance of composite is higher than that of pure SBR and the values increases with the increase in concentration of fillers. The pure SBR has LOI value of 16, whereas composite with 20 phr exhibit a LOI value of 20.4. The enhanced interaction between fly ash and the polymer may improve the flame retardency of composite by the improved dispersion level and heat flow resistance. Thus, dispersion of fly ash particles in the polymer is an important criterion for obtaining improved flame retardency [14]. If metal oxide particles, such as $Al_2O_3$, $Fe_2O_3$, $K_2O_3$, $SiO_3$, etc., are present in the surface of fly ash particles, the carbonization of polymer is reduced forming more protective char layer that leads to improved flame retardency behavior of the composite.

## CONCLUSIONS

Zinc and calcium silicate modified fly ash was successfully prepared and characterized by FTIR and XRD measurements. Unmodified and modified fly ash particles incorporated in SBR composite were prepared by adding various loading of fly ash in a two-roll mixing mill. The cure characteristics, morphology, crystalline nature, mechanical properties, thermal stability and flame resistance of fly ash filled SBR was studied. Cure characteristics of the composite showed that the optimum cure time and scorch time decrease with loading of filler, whereas the rheometric torque increased with loading of fly ash particles. Surface modification on fly ash improved the processability of SBR composite as compared to unmodified fly ash/SBR samples. The XRD patterns of modified fly ash/SBR composite showed few peaks of modified fly ash along with the amorphous peak of SBR. SEM images showed that the composite with 30 phr fly ash filled SBR showed better dispersion of filler. Thermal stability and flame resistance of the composite was higher than that of pure SBR. The mechanical properties such as tensile strength modulus and tear resistance were found to be increases with increase in loading of fly ash particles up to 30 phr, and thereafter the properties decreased. Hardness increases where as the resilience decreases with increase in loading of fillers. Surface modified fly ash was able to give an enhancement in cure and mechanical properties of SBR composites in comparison with the modified fly ash SBR composite.

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# Ozone in the Stratosphere: An Environmental Accumulation and Flow

**Ronald C. Persin**
College of Education – Florida Atlantic University | Boca Raton, FL 33431
*(E-mail: rpersin@fau.edu)*

**Abstract:** This article is concerned with the derivation of a set of differential equations that may contribute to the understanding of the formation of the ozone layer in the stratosphere. In the stratosphere, at an elevation extending from 10 to 50 kilometers, is where the planet's naturally occurring ozone gas filters the sun's ultraviolet (UV) radiation. Ozone abundances in the stratosphere seem to be determined by the *balance* between chemical processes that produce ozone and processes that destroy ozone. This balance is itself determined by the concentrations of reacting gases and how the rate or effectiveness of the various reactions varies with sunlight intensity (photon flux), location in the atmosphere, temperature, and other factors.

**Key Words:** Chapman reactions, photochemistry, photon flux, Beer's Law.

## BACKGROUND

Ecological models of environmental systems that utilize mathematical methods use equations to describe behavior. The equations are then applied to (i) an accumulation and flow, or (ii) a feed-back loop [1]. The amount of ozone that accumulates in the stratosphere is determined by the interaction of oxygen ($O_2$) and light intensity (photon flux) from the Sun.

At this point in the project, oxygen-only chemistry will be used to estimate the ozone layer. Oxygen serves as both a creator and destroyer of ozone, according to the following equations:

$$\left.\begin{array}{l} \underset{\text{oxygen molecule}}{O_2} + \underset{(\leq 242\text{ nm})}{\text{uv light}} \longrightarrow \underset{\text{oxygen atoms}}{2(O)} \\[2ex] 2 \times (\, O + O_2 + \underset{\text{(energy absorber)}}{M} \longrightarrow \underset{\text{ozone}}{O_3} + M \,) \end{array}\right\}\begin{array}{c}(1.1)\\ \text{production}\\ \text{equations}\\ (1.2)\end{array}$$

$$\text{Net: } 3O_2 + \text{uv light} \longrightarrow 2(O_3) \qquad (1.3)$$

The above equations represent the first successful attempt to quantitatively understand the photochemistry of ozone by S. Chapman in 1930 [2]. He proposed that $O_3$ is created by the dissociation of $O_2$ to form O atoms, followed by the reaction between O and $O_2$. The workings of the production equations are illustrated in Figure 1.

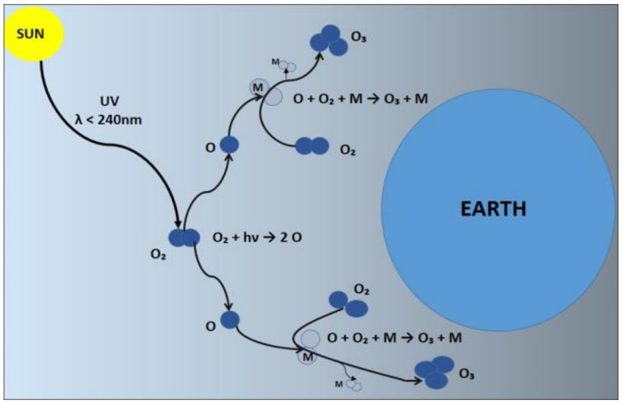

**Fig 1. The Production of Ozone Based on the Chapman Reactions.**

Most of the photolysis of $O_2$ in the stratosphere occurs at wavelengths in the Schumann-Runge bands (175-200 nm) and the Hertzberg continuum (extending to 242 nm) [3].

$O_3$ is destroyed by ultraviolet photons or the direct reaction between $O_3$ and O:

$$\left.\begin{array}{l} O_3 + \text{uv, visible light} \rightarrow O + O_2 \\ \text{(low energy ultraviolet or visible)} \\ O_3 + O \longrightarrow O_2 + O_2 \end{array}\right\} \begin{array}{l} (1.4) \\ \text{depletion equations} \\ (1.5) \end{array}$$

In addition to these, Chapman discussed several other reactions now known to be unimportant. The set of reactions, (1.1) to (1.5), known as the Chapman reactions, form the cornerstone of stratospheric $O_3$ chemistry [4].

Considering just the Chapman reactions, the lifetimes 1/L of $O_3$ and O for typical mid-latitude lower-stratospheric conditions are 1000 seconds and .002 seconds, respectively. The loss of $O_3$ is dominated by photolysis, while the loss of O atoms is dominated by reaction with $O_2$ to form $O_3$.

The lifetime of $O_3$ is 103 – 106 times greater than the lifetime of O in the stratosphere. Other constituents have lifetimes of days, weeks, months, or longer, many orders of magnitude longer than the lifetime for $O_3$. In addition, many phenomena of interest, such as the Antarctic ozone hole, mid-latitude trends, and perturbations from volcanoes, occur on time-scales of months to decades. As a result, the “ozone” problem involves time-scales ranging over 15 orders of magnitude. This leads to both conceptual and computational difficulties [5].

While $O_2$ is the only element that produces ozone, there are many other elements that destroy ozone. Most $O_3$ destruction takes place through catalytic processes rather than the Chapman Reactions. Ozone is a highly unstable molecule that readily donates its extra oxygen molecule to free radical species such as nitrogen, hydrogen, bromine, and chlorine. An example of a depletion equation of this type would be:

$$O_3 + X \longrightarrow XO + O_2$$
$$(\text{ where } X \text{ may be H, NO, Br, or Cl})$$

Since oxygen, $O_2$, is the only component of air that produces ozone (by photochemical and chemical reactions), this model, at first, will center on the $O_2$ molecule. The $O_2$ molecule consumes light energy to form ozone, so a model must be built for light intensity (photon flux) as a function of altitude by looking at how the presence of $O_2$ affects incoming light intensity from the sun.

## PRESSURE AS A FUNCTION OF ALTITUDE

We now turn our attention to the derivation of an equation for air pressure as a function of altitude, which will be used to obtain an equation for oxygen concentration as a function of altitude. It is this oxygen that is critical to the formation of ozone. Although it is fairly obvious that temperature varies with altitude, for the purposes of this project it will be assumed that temperature remains constant. Specifically, let’s assume that the air temperature is 285 Kelvin, which is an estimate of the global average air temperature near the surface of the earth.

We know that the pressure exerted by a gas or fluid varies directly with altitude and the density. Atmospheric chemists refer to the mathematical relationship describing this phenomenon as the barometric equation. The barometric equation states that the rate of change in pressure, P, relative to altitude, a, is proportional to the density, ρ, rho (mass per unit volume) of the fluid (in this case, air) where the proportionality constant is the negative of the acceleration due to gravity, g:

$$\frac{dP}{da} = -g\rho$$

Now, using the Ideal Gas Law, which states that:

$$PV = nRT$$

where:

- V is volume measured in m$^3$,
- T is the temperature at the earth's surface measured in Kelvins (K),
- P is pressure measured in kg / (m sec$^2$) (also referred to as newtons / m$^2$),
- n is the number of moles of gas (1 mole = 6.022 x 10$^{23}$ molecules), and
- R is the gas constant measured in m$^2$kg / (sec$^2$·K·mole).

If we divide the mass of gas, m (kg), by its molecular weight, M (kg/mole), we obtain the number of moles of gas. This expression can be substituted for n = m/M, and upon rearranging we get:

$$\frac{m}{V} = \frac{PM}{RT}$$

Note that m/V is the definition of density and is denoted as ρ.

Since we are formulating an expression for the density of air, which is a mixture of several gases, we will use an average molecular weight of air, $M_{air}$, which we will calculate shortly. $M_{air}$ is measured in kg/mole. We will assume for the purposes of this project that g, R, $M_{air}$, and T are constant relative to altitude.

The previous assumptions do not appear to be too far-fetched since most ozone is present at between 10-40 km altitude. All that is left is to solve the differential equation to obtain an expression for P(a) describing pressure as a function of altitude. We now have,

$$\frac{dP}{da} = \frac{-gPM_{air}}{RT}$$

After separation of variables, integrating, and evaluating the constant, we get a result

$$\mathrm{P(a)} = P_0 e^{\frac{-gaM_{air}}{RT}}$$

with $P_0$ = 1.013 x $10^5$ N/$m^2$ , representing the initial pressure which is the pressure at the Earth's surface (a = 0). Now let:

$$\mathrm{H} = \frac{RT}{gM_{air}}$$

Atmospheric chemists refer to the combined parameter H as the scale height. Recall that the pressure (and thus, density) of air decreases with increasing altitude. The scale height, H, can be thought of as the height the entire atmosphere would have if its density were constant at the sea level value throughout.

We can compute the scale height, H, by determining the values of each of its parameters. $M_{air}$ can be calculated from the fractional composition and the molecular weight of each component in the air by taking a weighted average. Table 1, below, lists the significant chemical components of air along with their individual fractional amounts [6] and molecular weights [7].

**Table 1: Average composition of the most abundant gases in the atmosphere**

| Gases | Fraction of Air | M (kg/mole) |
|---|---|---|
| $N_2$ | 0.78080 | 0.028013 |
| $O_2$ | 0.20950 | 0.031999 |
| Ar | 0.00930 | 0.029948 |
| $CO_2$ | 0.00034 | 0.044010 |

The values shown in Table 1 are those for the most abundant gases in dry air. It is understood that atmospheric air also contains water vapor. The amount of water vapor can vary from place to place, but the concentration of water vapor decreases with altitude, and above an altitude of about 10 km, atmospheric air consists of only dry air [8]. Therefore, the presence of water vapor in the atmosphere, particularly in the stratosphere, is being neglected.

If we assume that near the earth's surface the global average air temperature is 285 K, the gas constant, R, is 8.3144 $m^2$kg/(sec$^2$ K Mol), and the acceleration of gravity, g, is 9.80 m/s$^2$ then H ≈ 8400 m. So we now have the equation for pressure as a function of altitude as:

$$\mathrm{P(a)} = 1.013\mathrm{x}10^5\ \mathrm{N/m^2} \cdot e^{-a/8400\ \mathrm{m}} = \mathrm{P_o} \cdot e^{-a/8400\ \mathrm{m}}$$

According to this equation, the pressure would drop in a logarithmic fashion as altitude increases. Up to 40 km, we have 99% of atmospheric mass, and the upper boundary at which gases disperse into space is approximately at 1000 km above sea level. A plot of the above equation is shown in Figure 2.

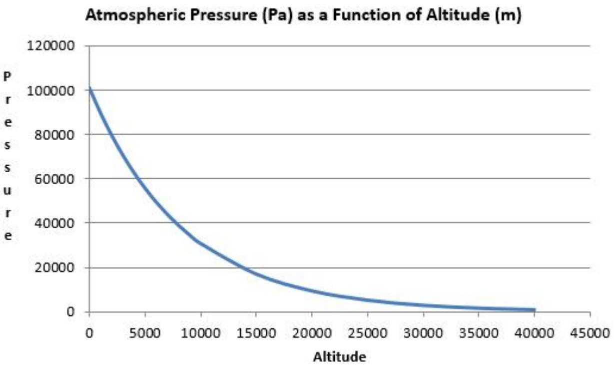

**Fig 2. This graph shows that atmospheric pressure decays exponentially from its value at the surface of Earth**

## OXYGEN AS A FUNCTION OF ALTITUDE

Now we shift our focus from pressure as a function of altitude to concentration of oxygen as a function of altitude. To accomplish this, it is assumed that pressure and concentration of oxygen can be related through the Ideal Gas Law:

$$\frac{n}{V} = \frac{P}{RT}$$

The left hand side, $\frac{n}{V}$, is in moles / m$^3$ but atmospheric chemists seem to prefer to work in units of (molecules / m$^3$), so the concentration quantity from the above equation should be multiplied by Avogadro's number, 6.022 x $10^{23}$ (molecules / mole). Additionally, not every air molecule is an oxygen molecule, $O_2$, so in order to obtain an expression for concentration of $O_2$ , we also need to multiply the concentration of air by the fractional abundance of $O_2$ in the air, which is 0.2095 (given in Table 1).

We can now express C(a) as the concentration of oxygen at a given altitude by the following equation:

$$C(a) = C_o \cdot e^{\frac{-a}{H}} \text{ , with } C_o = 5.4 \times 10^{24} \text{ molecules/m}^3$$

Here, $C_o$ represents the concentration of $O_2$ at altitude a = 0, sea level.

The results of this derivation are illustrated as a plot in Figure 3, which shows that the concentration of oxygen decays exponentially from its value at the surface of Earth.

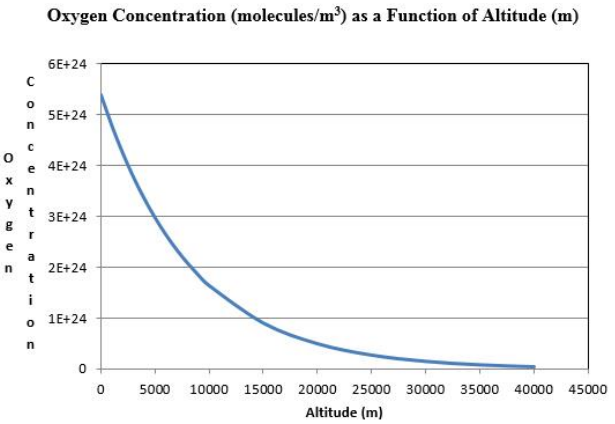

**Fig 3. This graph shows that oxygen concentration decays exponentially from its value at the surface of Earth**

## FORMULATION OF A DIFFERENTIAL EQUATION FOR PHOTON FLUX I AS A FUNCTION OF ALTITUDE

Let us consider passing light of a single wavelength through a substance that tends to absorb light. It makes sense from a qualitative point of view that the intensity of the light (or photon flux) should diminish as the light travels through the substance. In essence, the more light-absorbing molecules with which the incident light comes into contact, the more the light intensity decreases.

There are two important parameters that determine how many light-absorbing molecules a given incident light will contact. The first is the concentration of the absorbing molecules. As the concentration increases, the light intensity will be attenuated by a greater amount. The second parameter is the length of the path the light takes through the absorbing medium. As the path length increases, the light will come into contact with more absorbing molecules, and thus the light intensity will diminish.

There is yet another term that greatly affects how light is absorbed by a substance. In this report, the term is called the absorption cross section, σ. This term can be thought of as the ability of a particular molecule to absorb light of a certain wavelength.

To formulate a differential equation that examines the *change in photon flux* relative to *change in altitude*, we use a form of Beer's Law, which states that the rate of change in photon flux relative to altitude is the product of the amount of photon flux present, the concentration of light absorbing species present at a particular altitude, and the ability of the absorbing species to absorb light of a certain wavelength. This is described by the differential equation:

$$\frac{dI}{da} = I(a) \cdot C(a) \cdot \sigma$$

where,

- I(a) = photon flux at altitude, a
- C(a) =concentration of absorbing species at altitude, a
- σ = absorption cross section of the absorbing species.

Beer's Law is usually expressed with a negative sign on the right side of the equation, but in our model the negative sign is dropped because of the referencing system for altitude and photon flux. Recall that our mathematical model describes the photon flux, I, as a function of altitude, a, and assumes that the only absorber of light is the oxygen molecule, $O_2$.

Now we chose 240 nm as the wavelength of light for our model because it is in the ultraviolet range of light where oxygen absorbs most readily. The value for the absorption cross section of $O_2$ at this wavelength is $1.0 \times 10^{-28}$ $m^2$ [9]. The photon flux from the sun at this wavelength, $I_0$, is $7.61 \times 10^{17}$ photons/($m^2$sec).

Now we combine Beer's Law with our previous equation for C(a) and use separation of variables to solve for I(a). The initial condition is that $I(a) = I_0$ when $a \to \infty$ (top of the atmosphere). Therefore, we get:

$$I = I_o \cdot k^{e^{(-a/H)}}$$

where:

- I = amount of light with absorber present
- Io = amount of light with no absorbers
- σ = absorption cross section (m2/molecule)
- H ≈ 8400 m, scale height
- a = altitude
- k = e(-σ·C0·H) ≈.01072

The results of this derivation are shown as a plot in Figure 4. Solar photon flux is increasing with altitude from the surface of Earth to its maximum value at $I_o$.

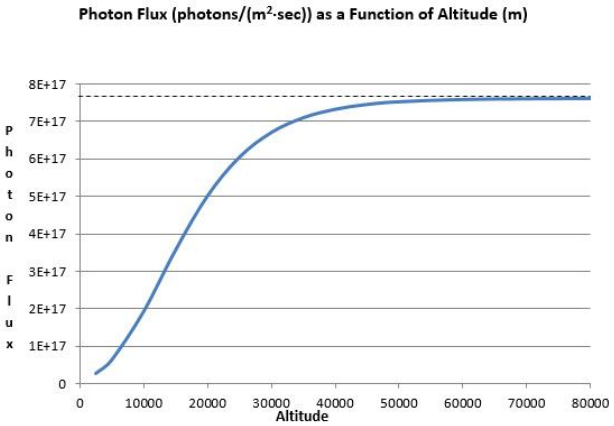

**Fig 4. This graph shows photon flux as a function of altitude, for a single 240 nm wavelength, asymptotically approaching $I_o$.**

## SUMMARY & CONCLUSION

Ozone abundances in the stratosphere are determined by the *balance* between chemical processes that produce ozone and processes that destroy ozone. This balance is itself determined by the amounts of reacting gases and how the rate or effectiveness of the various reactions varies with sunlight intensity (photon flux), location in the atmosphere, temperature, and other factors.

As we examine the graphs of oxygen concentration and photon flux, both as functions of altitude, reasons for the abundance of ozone in the stratosphere seem to be apparent. It is in this layer of the atmosphere, between 10,000 and 50,000 meters, that the conditions for ozone formation are maximized. At higher altitudes there is apparently not oxygen available for this reaction to take place. As for lower levels, the photolysis of oxygen is dependent on the availability of very short-wave sunlight and in lower layers of the stratosphere there is a shortage of the necessary short wavelength light because much of it is absorbed higher up in the atmosphere. Oxygen, $O_2$, consumes light energy and it does this most efficiently at 240 nm to form ozone, $O_3$. The mechanism for stratospheric ozone formation, photolysis of $O_2$, does not take place in the troposphere because the strong UV photons needed for this photolysis have been absorbed by $O_2$ and ozone in the stratosphere. It is this process (as well as others that are not part of this project) that allows ozone in the stratosphere to be maintained, and subsequently to filter-out ultraviolet radiation.

For activities to help students understand the importance of the ozone layer, as well as its formation and depletion, several references [10,11,12,13] are provided.

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# Undergraduate Research Engagement Among STEM Majors

**Susan Carol Losh* and Brandon J. O. Nzekwe**
*Florida State University | Tallahassee FL 32306*
*(*E-mail: slosh@fsu.edu)*

**Abstract:** We examine facets of a researcher identity and attitudes towards a research career among several hundred physical and life science, engineering and mathematics (STEM) undergraduates at a large public Southeastern university We address how a researcher identity and researcher career attitudes relate to student awareness of university research opportunities, interest and research involvement. Special attention is paid to first generation college students and major undergraduate field, and to the effects of gender and ethnicity. Gender, ethnicity, college major, and first generation college student status influence facets of a researcher role-identity. The results may help explain undergraduate attitudes toward and identification with prospective STEM occupations as well as student awareness, interest, and involvement in research.

**Key Words:** STEM.

## INTRODUCTION

*Undegraduate research experiences*, i.e., activities enabling students to perform intellectual investigations that contribute to disciplinary knowledge, are high-impact education practices. Through senior theses, research assistantships, internships, or independent projects, "apprentices" may review literature, assist in data collection or data analysis [1] in an interactive process with professionals [2].

Research engagement is one form of student involvement in college academic and social aspects that predicts persistence in college, baccalaureate completion or advanced degree aspirations [2-8], partly as a result of engagement and interaction with faculty. Research experiences can promote career marketability and career identification. Some pundits even assert that *all* undergraduates should have research opportunities [9,10], yet overall by senior year only about 20% have participated [11].

We address *researcher identity salience and career attitudes* among science, math and engineering (STEM) undergraduates, which may help explain how potential professionals pursue and sustain career goals. We study how student knowledge about research opportunities, interest, and their experiences relate to identifying as a researcher and career attitudes. We consider or control the effects of gender, ethnicity, college class level, and first generation college status, comparing physical science, life science, engineering, and computational science majors.

## BACKGROUND

Many scholars believe that undergraduate research participation provides educational and career advantages [2,5,12,13], but few examine *why* students participate or *who* participates [3,10,14]. Fewer still have studied whether students identify with a future research career [15,16]. Most such studies focus on STEM majors, as we do here.

***Undergraduate research involvement.*** In seeking to invigorate undergraduate studies, the Boyer Commission [17] proposed that student research involvement assume a central role (see also, American Council of Learned Societies, 2007; National Survey of Student Engagement, 2007) [18,19]. Federal initiatives now encourage such experiences, e.g., the National Science Foundation (NSF) sponsors Research Experiences for Undergraduates in diverse areas.

Such activities let students more closely identify with research-intensive careers [2,13]. Theoretically, we define the extent of this identification as *researcher role-identity salience*, i.e., whether someone aspires to a researcher role and is motivated to perform role anticipatory behaviors [20,21,22].

Research participation can foster *situated learning* [1] and shape a researcher role-identity by refining and/or modifying attitudes and stabilizing student identities as prospective occupational incumbents [2]. Research experience enables undergraduates to learn first-hand *in context* [23,24], not only teaching them *how* to do research, but also providing a practice forum through authentic apprenticeships [12,13].

Why don't more undergraduates participate? Many say that they lack time or interest, underestimate the importance of research, are unaware of opportunities, or see few incentives [10,14]. Students who do engage in research tend to be more motivated, knowledgeable about opportunities, or initially more interested [25,26], suggesting self-selection effects, and a reciprocal relationship between research interest and behavior.

***Science and technology students.*** Undergraduate STEM majors form one-third of baccalaureates [27]. Concurrently, the STEM workforce has expanded: its 2004 to 2007 growth (3.2%) doubled that of the U.S. labor force, partly due to new areas (e.g., forensic anthropology), greater supply, immigration, and relatively low scientist and engineer retirements [27]. Thus, STEM undergraduates face a competitive labor market in which research experience can confer a competitive edge.

Undergraduate research interns report that these experiences clarify career interests [12,13], increase research understanding, and foster ethical behavior *in situ* [2,3]. They also express how peer, mentor, and faculty interaction create a perceived acceptance within a science community. These gains often translate into positive attitudes toward working as a researcher. Given a strong science research tradition, frequent science undergraduate participation is unsurprising [9,10,28,29].

***Conceptual foundations: Researcher role-identity.*** A legitimate peripheral participant's transition to full membership within a community of practice entails a process of *role-identity development* [24] through situated learning [23,30]. For example, undergraduate interns enact the role-behaviors of a research scientist [2]. *Role-identity* describes role ownership through such conduct and self-identification [22,31]. When individuals use social roles as behavioral blueprints and self-defining mechanisms, roles become identities [20].

*Role-identity salience* describes hierarchically positioning discrete role-identities within the self-concept. Intrinsic and extrinsic gratifications achieved through performing valued role-behaviors can influence role-identity salience [31]. By enacting behaviors consistent with the social expectations of a role-identity, an individual expresses how they want others to regard them [32]. Students incline toward activities aligned with self-perceptions, making the self-concept germane to career decisions [21], e.g., joining science clubs or assisting with a professor's research, all in the expectation of becoming scientists.

*Situated role-identities* activate when behavior is oriented toward a particular social role [32,33]. Empirical research suggests that role-identity salience relates to: role importance, self-perceived others' expectations about one's role enactment; commitment to a role through contingent social relationships, and involvement to role-related activities [30]. Callero's (1985) study about blood donors presents quantifiable measures of role-identity salience, which we draw upon for our present study [20].

Individual actions provide a platform that others use to judge when appropriate role-behaviors are performed [34]. Thus, the evaluations of important others may support individuals in these behaviors. If an individual vacates a particular role, they may incur social losses because many of their important relationships were predicated on role occupation [20,22,35,36]. Hurtado et al. [16] argue that undergraduate research experiences foster mentor and peer support networks for students seeking further research involvement. Commitment also exists in research efforts, especially the allocation of discretionary time [20,30,37,38].

***Career Attitudes.*** Gender, ethnicity, and first generation college status influence role identities. Some indirect evidence comes from research on undergraduate career attitudes, which has one focus on increasing female and minority representation in the sciences [16,39-41]. For example, Carlone and Johnson [15] found that being recognized as a "science person" by others helped strengthen women's science identities.

Sex stereotypes about "appropriate" gender occupations begin at least by elementary school [7,42,43], continuing into middle school [44,45,46]. Other evidence suggests that African-American, Hispanic American, or working class students, who are more often first generation undergraduates, become more easily discouraged in college science courses (e.g., see Harackiewicz, Canning, Tibbetts, Giffen, Blair, Rouse, & Hyde, 2013)[47].

## RESEARCH QUESTIONS

1. How do researcher identity salience and research career attitudes relate to awareness, interest, and involvement in research activities among undergraduate STEM majors?
2. How do awareness, interest, involvement, researcher identity salience, and research career attitudes compare among physical or life sciences, engineering and mathematics majors?
3. How do gender, ethnicity, first generation college student status, and college year relate to researcher identity and career attitudes?

We anticipate that STEM majors *interested* in research will *know more* about undergraduate research opportunities; *interest* and *awareness* should positively correlate with *involvement*, which in turn should positively correlate with a r*esearcher identity.* Such an *identity* should correlate with *positive research career attitudes*.

## METHODS

Under the auspices of a public southeast university Office of Undergraduate Research, all undergraduates (N = 30,744) in Spring, 2013 received an email invitation to complete an online survey on "undergraduate experiences". Items tapped demographics, attitudes toward research and a research career, and research experience. We collected data over four weeks with several email reminders sent by the university; 7,469 undergraduates (24%) completed virtually all the questionnaire.[1] Through the university office, which not only fielded the survey but also provided basic information on major, gender, ethnicity, and other variables, we can identify areas of survey over and under response to compare with self-reports.

We categorized majors according to the university's schools and colleges, augmented with information from the NSF's *Science and Engineering Indicators* (2014)[27]. Because there would be too few cases for multivariate analyses, we did not use finer divisions. **Physical science** majors included: biochemistry, chemistry, geology, meteorology and physics; biological sciences constituted the **life science** majors. **Engineering** included chemical, civil, computer, electrical, environmental, industrial, and mechanical engineering, and **computational sciences** included actuarial science, biomathematics, computer science, mathematics, and statistics.

***Participants.*** Here, we concentrate on 1539 physical science, life science, engineering and mathematics undergraduates, who completed most of the online questionnaire. Table 1 presents basic data for these participants. With the exception of an overrepresentation of Asian-American students (who more often choose STEM majors in the university) and a slight underrepresentation of White American students, gender and ethnic distributions reflect the larger university. Perhaps indicating their desire to learn more about research opportunities, freshmen aspiring STEM majors are overrepresented, while upper classmen are underrepresented. In proportion to their numbers among university STEM majors, life sciences students are overrepresented while engineering and math majors are underrepresented. Nearly half (44%) were first generation college students.

***Measures.*** We operationalized *researcher role-identity* through: *CENTRALITY* (role-identity importance); *CONSTRAINED* (self-perceived expectations of significant others); *CONNECTED* (interpersonal connections through research activities); and *COMMITED* (time and involvement in research activities). These measures were derived from Burke and Reitzes, Callero, Stryker and Serpe, and Thoits [20,30,37, 48].

To tap attitudes toward a research career, we slightly revised items that we had previously used listing "scientist" instead of "researcher" [49]. We could not find an "attitudes toward a research career" scale—indeed it is difficult even to find a measure of attitudes toward a *science* career [50].[2] Thus, we adapted items from Fraser's (1981) Test of Science Related Attitudes (TOSRA)[51], and added single items on awareness, interest, and overall participation in undergraduate research activities, and the likelihood of choosing a research career. Table 2 displays these items. Independent variables include: gender; ethnicity; and first generation college student status. We code college major as physical sciences, life sciences, computational sciences, and engineering.

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[1] We lose about one-sixth of this group on several research items, probably reflecting low familiarity, especially among younger students.

[2] Many instruments measure student attitudes toward science (e.g., Aikenhead & Ryan, 1992), but do not address assuming a science career.

**Table 1: Demographic comparison of all university undergraduates with study STEM participants**

| | Categories | All univ. undergraduates | | Study participants | |
|---|---|---|---|---|---|
| | | N = 30,744 | % | n = 7,469 | % |
| Gender | Women | **16,952** | **55.1%** | **824** | **53.5%** |
| | Men | **13,792** | **44.9** | **715** | **46.5** |
| Race/ Ethnicity | Asian/Pacific Islander | 1,138 | 3.7% | 103 | 6.7% |
| | Black/African American | 3,074 | 10.0 | 136 | 8.8 |
| | Hispanic/Latino | 4,946 | 16.1 | 260 | 16.9 |
| | Native American | 341 | 1.1 | 15 | 1.0 |
| | White/Caucasian | 20,818 | 67.7 | 1005 | 65.3 |
| | Other/Unspecified | 427 | 1.4 | 20 | 1.3 |
| Academic Classification | Freshman | 3,216 | 10.5% | 556 | 22.0% |
| | Sophomore | 6,293 | 20.5 | 1,382 | 18.6 |
| | Junior | 8,960 | 29.1 | 2,069 | 24.2 |
| | Senior | 12,260 | 39.9 | 3,460 | 35.2 |
| Academic Field | Physical sciences | 956 | 17.0% | 262 | 16.9% |
| | Life sciences | 1,948 | 34.7 | 517 | 42.8 |
| | Engineering | 1,704 | 30.3 | 376 | 24.3 |
| | Computational sciences | 1,011 | 18.0 | 246 | 16.0 |

## DATA ANALYSIS

We created salience and career attitudes indices from Confirmatory Factor Analysis (CFA) model loadings,[3] shown with the items in Table 2. Cognizance, Interest, Experience, Identity, and (career) Choice are single items (Table 2).

Thirty-five percent of these STEM students had research participation, slightly (but not significantly) more prevalent among men (36%) than women (33%). Asian American students most often participated in research (44%), followed by White (36%), Latino/a (31%) and Black American (26%) students ($X^2_{(3)} = 9.72$, $p = .02$; Cramer's V = 0.08). Continuing generation students more often engaged in research than first generation collegiates (37 vs. 31%, $p < .01$; Cramer's V = 0.07). Forty-four percent of physical science majors participated in research, compared with 36% of life science students, 34% of engineering majors and only 20% of computation science majors ($X^2_{(3)} = 36.23$, $p < 0.001$; Cramer's V = 0.15). Participation increased steadily from freshmen (18%) through fifth year seniors (50%; $X^2_{(4)} = 103.57$, $p < 0.001$; Cramer's V = 0.26). ***Bivariate correlations among cognitive items*** are shown in Table 3. All correlations are positive; some are exceptionally strong. Generally, correlations for felt expectations from others to enter research more strongly correlate with identity salience and the likelihood of a research career (but *not* with positive career attitudes) than those with one's social networks through research. These students indeed may feel constrained by expectations, perhaps from family, to become research scientists even if their feelings about that career are lukewarm. Correlations among the Centrality, Constrained and Committed indices are high, and exceed those for research Connections, suggesting that for undergraduate STEM majors, current social relations (e.g., faculty) play a lesser part in keeping students on a path to a research career than supposed.

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[3] The model for this study had a $X^2_{(66)} = 482.89$, $p < 0.001$, a CFI and a TLI both greater than 0.95, a RMSEA index under 0.05, and an SRMR under 0.1. Because the Likelihood ratio Chi-square, like all probability distributions, is sensitive to sample size, we first identified this model using a hypothetical sample size of 500, which produced $X^2_{(66)} = 55.88$, $p = 0.808$, which, if anything, was "over fitted".

**Table 2: Questionnaire items used in this study Factor loadings from Confirmatory Factor Analyses (CFA) are shown in the far left-hand column**

| Loadings | CENTRALITY of researcher identity | |
|---|---|---|
| 1.000 | SCITHNK | Doing research is something I rarely even think about. |
| 1.480 | FEELLOS | I would feel a loss if I were forced to give up doing research. |
| 0.690 | NOCLR | I really don't have any clear feelings about doing research. |
| 1.764 | IMPTPRT | Doing research is an important part of who I am. |

| Loadings | CONSTRAINED by perceived expectations of others | |
|---|---|---|
| 1.000 | INTRMS | Many people think of me in terms of being a researcher |
| 1.116 | IMPTME | Other people think that doing research is important to me |
| 0.957 | FRDSREL | It is important to my friends and relatives that I continue as a researcher |
| 0.703 | EXPECT | Many of the people that I know expect me to continue as a researcher |
| 0.606 | DISAPPT | Many people would probably be disappointed in me if I just decided to stop doing research. |

| Loadings | CONNECTED through research activities | |
|---|---|---|
| 1.000 | APRXKNW | Approximately how many people do you know through doing research in your field of study |
| 0.415 | IMPTYOU | Of all the people you know through doing research, how many are important to you? |
| 0.394 | OTHRACT | Of the people you know through doing research, how many participate in other activities with you? |

| Loadings | COMMITED through time and research involvement | |
|---|---|---|
| 0.903 | TMSPNT | I spend much of my time doing research. |
| 1.000 | HVRSCH | I am heavily involved in research-related activities. |

| Loadings | CAREER Interest/Attitudes | |
|---|---|---|
| 0.805 | DULBOR | A career in research would be dull and boring. |
| 0.707 | INTRSJB | A job as a researcher would be interesting. |
| 0.624 | DSLKCAR | I would dislike having a career in research. |

| Single items | |
|---|---|
| IDENTITY | Being a researcher is an important part of my identity |
| Career CHOICE | I am likely to choose a career in research. |
| COGNIZANCE | How much do you feel you know about undergraduate research activities/programs? |
| INTERESTED | How interested are you in participating/continuing your participation in research activities? |
| EXPERIENCE | Have you ever worked with a mentor/faculty supervisor on research-related activities? |

## Table 3: Correlations among research indices and items

| | COGNIZANT | INTEREST | EXPERIENCE | CENTRAL | CONSTRAINT | CONNECTED | COMMITTED | IDENTITY | CAREER | CHOICE |
|---|---|---|---|---|---|---|---|---|---|---|
| **COGNIZANT** | 1.00*** | | | | | | | | | |
| **INTEREST** | 0.17*** | 1.00*** | | | | | | | | |
| **EXPERIENCE** | 0.45*** | 0.13*** | 1.00*** | | | | | | | |
| **CENTRAL** | 0.32*** | 0.58*** | 0.34*** | 1.00*** | | | | | | |
| **CONSTRAINT** | 0.28*** | 0.33*** | 0.31*** | 0.60*** | 1.00*** | | | | | |
| **CONNECTED** | 0.29*** | 0.10*** | 0.35*** | 0.28*** | 0.24*** | 1.00*** | | | | |
| **COMMITTED** | 0.37*** | 0.23*** | 0.42*** | 0.60*** | 0.67*** | 0.35*** | 1.00*** | | | |
| **IDENTITY** | 0.23*** | 0.35*** | 0.26*** | 0.62*** | 0.80*** | 0.20*** | 0.60*** | 1.00*** | | |
| **CAREER** | 0.11*** | 0.48*** | 0.15*** | 0.56*** | 0.35*** | 0.14*** | 0.22*** | 0.40*** | 1.00*** | |
| **CHOICE** | 0.20*** | 0.37*** | 0.22*** | 0.60*** | 0.60*** | 0.20*** | 0.55*** | 0.61*** | 0.58*** | 1.00*** |

Minimum n = 1166 *p <.05 **p< .01 ***p< .001

The largest correlations with a research identification and career likelihood are with the felt centrality of doing research, others' expectations, and research involvement. The latter, of course, may be anticipatory socialization to prepare for graduate school or the occupational marketplace. Surprisingly, correlations with career likelihood are lower for knowledge about research opportunities, interest in research engagement—or even research experience.

***Bivariate synopses.*** *Gender and ethnicity.* The effects of gender, ethnicity, college generational status, and major on Cognizance, interest, and participation are shown in Tables 4, 5 and 6. Women STEM majors were as cognizant, interested, and as likely to have had at least some research experience as men. First generation students felt they knew less about research opportunities and (as noted earlier) perhaps as a consequence, participated less often.

## Table 4: Mean Score Cognizant Research Opportunities (high = 4)

| **Correlated Variable** | $\bar{y}$ | **Statistical Results** | ***n*** |
|---|---|---|---|
| Female | 2.54 | $t_{(1475)} = 0.08$ ns | 798 |
| Male | 2.54 | $\eta = 0.00$ | 679 |
| White | 2.52 | $F_{(3,1473)} = 4.62$ $p = .003$ | 993 |
| African American | 2.39 | $\eta = 0.10$ | 134 |
| Hispanic American | 2.61 | | 253 |
| Asian American | 2.77 | | 97 |
| First generation college | 2.43 | $t_{(1475)} = 4.10$ $p < .001$ | 645 |
| Continuing generation | 2.62 | $\eta = 0.11$ | 832 |
| Physical science major | 2.67 | $F_{(3,1473)} = 13.87$ $p < .001$ | 255 |
| Life science major | 2.65 | $\eta = 0.17$ | 629 |
| Engineering major | 2.39 | | 359 |
| Computational science major | 2.34 | | 234 |

### Table 5: Mean Score Interest in Research Opportunities (high = 4)

| Correlated Variable | $\bar{y}$ | Statistical Results | *n* |
|---|---|---|---|
| Female | 2.86 | $t_{(1399)} = 0.15$ ns | 759 |
| Male | 2.85 | $\eta = 0.00$ | 642 |
| White | 2.77 | $F_{(3,1397)} = 11.84$ $p < .001$ | 940 |
| African American | 2.75 | $\eta = 0.16$ | 128 |
| Hispanic American | 3.17 | | 242 |
| Asian American | 3.11 | | 91 |
| First generation college | 2.90 | $t_{(1399)} = 1.35$ ns | 616 |
| Continuing generation | 2.82 | $\eta = 0.04$ | 785 |
| Physical science major | 3.02 | $F_{(3,1397)} = 17.17$ $p < .001$ | 239 |
| Life science major | 3.00 | $\eta = 0.19$ | 596 |
| Engineering major | 2.77 | | 340 |
| Computational science major | 2.46 | | 226 |

### Table 6: Did Student Participate in Research?

| Correlated Variable | % Yes | Statistical Results | *n* |
|---|---|---|---|
| Female | 33 | $t_{(1516)} = 1.02$ ns | 817 |
| Male | 36 | $\eta = 0.03$ | 701 |
| White | 36 | $F_{(3,1479)} = 3.25$ $p = .02$ | 995 |
| African American | 26 | $\eta = 0.08$ | 134 |
| Hispanic American | 31 | | 253 |
| Asian American | 44 | | 101 |
| First generation college | 31 | $t_{(1516)} = 2.67$ $p = .008$ | 666 |
| Continuing generation | 37 | $\eta = 0.07$ | 852 |
| Physical science major | 44 | $F_{(3,1514)} = 12.34$ $p < .001$ | 269 |
| Life science major | 36 | $\eta = 0.15$ | 650 |
| Engineering major | 34 | | 368 |
| Computational science major | 20 | | 241 |

Asian American STEM majors felt the most knowledgeable about research opportunities, and nearly half had had a research experience. On the other hand, fewer African American and Latino/a STEM majors had research experience, although Hispanic American students had expressed the greatest interest in research engagement.

Physical and life science majors felt equally knowledgeable and interested in research opportunities than engineering majors, although physical science majors more often had actual research experience. On the other hand, computational science majors were the least interested in research opportunities and were least likely to participate—with less than half the participation rate of physical science majors.

*Multivariate analyses.* We examine how gender, ethnicity, first generation, student status and major influence facets of a researcher role identity and research career attitudes in a series of n-way analyses of variance. We also control for year in college, since seniors, unsurprisingly, have had more research experience than freshmen.

To illustrate net effects of these variables, we use a presentation program often linked to ANOVA: Multiple Classification Analysis (MCA). MCA adjusts for other correlated factors and covariates in an ANOVA equation, to produce "net effects". MCA is recommended here because several of these predictors are intercorrelated. For example, women were over twice as likely as men to major in a biological science (58 vs. 26%), while men were almost three times more likely to major in engineering (36 vs. 14%) and nearly twice as likely to major in a computational science (21 vs. 11%, $X^2_{(3)} = 192.40$, $p < 0.001$; Cramer's V = 0.35).

Although Asian Americans most often majored in a physical science (24%), while White (24%), Black (29%), and Hispanic (24%) American students more often majored in engineering, these were essentially chance fluctuations ($X^2_{(9)} = 10.61$, $p = 0.30$). However, first generation students more often than continuing generation students majored in engineering (28 vs. 21%) or computational science (20 vs. 13%) but less often majored in life sciences (37 vs. 47%, $X^2_{(3)} = 27.92$, $p < 0.001$; Cramer's V = 0.13). Males were more often first generation students than females (47 vs. 42%, $X^2_{(1)} = 4.24$, $p = 0.04$), and half or more of Black (64%), Hispanic (54%) and Asian (50%) Americans were first generation STEM majors compared with White Americans (38%, $X^2_{(3)} = 46.90$, $p < 0.001$; Cramer's V = 0.18).

**Table 7: Basic ANOVA Models on Research Career Cognitions+**

| Predictor ⇓ | Centrality $\bar{y}$ | Adjusted MCA $\bar{y}$ | Constraint $\bar{y}$ | Adjusted MCA $\bar{y}$ |
|---|---|---|---|---|
| Female* | 14.68 | 14.50 | 11.59* | 11.98 |
| Male | 15.18 | 15.38 | 12.20 | 12.33 |
| White*** | 14.64 | 14.66 | 11.73*** | 11.74 |
| African American | 14.21 | 14.25 | 11.31 | 11.32 |
| Hispanic | 15.73 | 15.68 | 12.04 | 12.02 |
| Asian | 16.49 | 16.37 | 13.70 | 13.57 |
| First Generation++ | 14.95 | 15.02 | 11.97 | 12.02 |
| Later Generation | 14.88 | 14.82 | 11.79 | 11.75 |
| Physical science*** | 15.77 | 15.74 | 12.52*** | 12.47 |
| Life science | 15.33 | 15.53 | 12.10 | 12.34 |
| Engineering | 14.52 | 14.30 | 11.46 | 11.22 |
| Computational science | 13.47 | 13.33 | 11.17 | 10.96 |
| η = 0.23 | n = 1280 |  | η = 0.21 | n = 1262 |

| Predictor ⇓ | Connected $\bar{y}$ | Adjusted MCA $\bar{y}$ | Committed $\bar{y}$ | Adjusted MCA $\bar{y}$ |
|---|---|---|---|---|
| Female | 5.73 | 5.81 | 4.47*** | 4.44 |
| Male | 6.50 | 6.41 | 4.90 | 4.94 |
| White | 6.42 | 6.32 | 4.58*** | 4.59 |
| African American | 5.62 | 5.57 | 4.42 | 4.41 |
| Hispanic | 4.43 | 5.01 | 4.85 | 4.86 |
| Asian | 7.50 | 7.15 | 5.42 | 5.36 |
| First Generation* | 5.06 | 5.24 | 4.69 | 4.70 |
| Later Generation | 6.89 | 6.75 | 4.66 | 4.64 |
| Physical science*** | 7.85 | 7.71 | 4.89*** | 4.86 |
| Life science | 6.33 | 6.84 | 4.78 | 4.92 |
| Engineering | 5.97 | 5.66 | 4.64 | 4.49 |
| Computational science | 3.68 | 2.96 | 4.20 | 4.08 |
| η = 0.28 | n = 1147 |  | η = 0.23 | n =1276 |

| Predictor ⇓ | Identity $\bar{y}$ | Adjusted MCA $\bar{y}$ | Career Attitudes $\bar{y}$ | Adjusted MCA $\bar{y}$ |
|---|---|---|---|---|
| Female** | 2.67 | 2.66 | 2.36 | 2.36 |
| Male | 2.87 | 2.88 | 2.40 | 2.40 |
| White*** | 2.71 | 2.71 | 2.35*** | 2.35 |
| African American | 2.67 | 2.68 | 2.33 | 2.33 |
| Hispanic | 2.84 | 2.84 | 2.45 | 2.45 |
| Asian | 3.21 | 3.18 | 2.59 | 2.57 |
| First Generation | 2.73 | 2.73 | 2.40 | 2.39 |
| Later Generation | 2.80 | 2.80 | 2.37 | 2.37 |
| Physical science** | 2.95 | 2.94 | 2.52*** | 2.51 |
| Life science | 2.76 | 2.82 | 2.36 | 2.37 |
| Engineering | 2.70 | 2.64 | 2.33 | 2.32 |
| Computational science | 2.64 | 2.60 | 2.37 | 2.36 |
| η = 0.19 | n = 1268 |  | η = 0.14 | n = 1279 |

+Except for "Identity", variables are composites (see Table 2); college class level is a control covariate.
++ Please see text for first generation interaction effects.
*p < .05 **p < .01 ***p <.001

### Table 8: Expressed Likelihood of Actually Having a Research Career+

| Predictor ⇓ | Likelihood Research Career $\bar{y}$ | Adjusted MCA $\bar{y}$ |
|---|---|---|
| Female* | 2.82 | 2.82 |
| Male | 2.99 | 2.99 |
| White | 2.87 | 2.87 |
| African American | 2.81 | 2.82 |
| Hispanic | 2.96 | 2.97 |
| Asian | 3.12 | 3.08 |
| First Generation++ | 2.90 | 2.90 |
| Later Generation | 2.90 | 2.90 |
| Physical science*** | 3.21 | 3.20 |
| Life science | 2.85 | 2.89 |
| Engineering | 2.85 | 2.81 |
| Computational science | 2.78 | 2.75 |
| η = 0.17 |  |  |
| n = 1279 |  |  |

+Single item indicator, high likelihood = 5.
++ Please see text for first generation interaction effects.

Male STEM students were more likely than female to see a research identity as central to their identity and more likely to feel high expectations from significant others. Male students also more heavily invested their time and effort in research activities, and were slightly more likely to agree that they would have a research career.

Asian American STEM students rated research as more central to their identity, felt more constrained by others' expectations, were more heavily invested in research activities, viewed a research identity as an "important part" of them, and held more positive attitudes toward a research career. Hispanic American students, currently seen as an under represented group in STEM majors and occupations, were close behind Asian American undergraduates, although they reported knowing the lowest number of individuals through research activities.

Physical science students were clearly the most motivated toward research: research was the most central to them, they felt the greatest level of expectations from others, were the most "connected" through research activities, expended the most time and effort in research activities, had the most positive research career attitudes, and were the most likely to assume a research career. Computational science students were consistently at the other end of the spectrum: feeling the least constrained by others' expectations, the least committed in terms of research time and effort, knew the fewest individuals through research activities, and rated research as the least central to their identity. However, their attitudes about a research career were comparable to life sciences or engineering majors. All the results reported in this section are net of other predictors and college class level.

Generational student status interacted with three other variables. First generation Black, Hispanic, and Asian American STEM majors exerted more time and effort in research activities than continuing generation STEM majors, while first generation White students exerted less ($F_{3,1244}$ = 3.70, p = .011). First generation physical and computation science majors held more positive attitudes about a research career than their continuing generation equivalents ($F_{3,1248}$ = 4.02, p = .007). Male first generation STEM majors rated research careers as more likely than continuing generation males, while female continuing generation STEM majors rated the likelihood of a research career higher than female first generation majors ($F_{1,1247}$ = 3.59, p = .058).

## DISCUSSION

We examined attitudes about and experience with undergraduate research, dimensions of researcher role-identity salience, and attitudes toward a research career among science and technology undergraduates. Background factors play some part in research affinity. Despite roughly equal knowledge of opportunities, interest and experience, male students were more involved and had higher researcher role-identity importance than females. It is possible that women, who among our participants were more often life science majors, may be aiming for advanced training in medicine—approximately 50% of medical students and 70% of veterinary students are female—and thus may be planning a clinical, rather than research, career. Future research should ascertain more clearly the career plans of women STEM undergraduates.

Asian American STEM students were consistently the most knowledgeable about and research opportunities, were most likely to have had undergraduate research experience, were the most interested in and behaviorally committed to research activities, and had the most positive research career attitudes. They also reported the greatest expectations from significant others to engage in research. Asian Americans are not generally defined as "under represented" in STEM fields, but Hispanic Americans are. Yet Hispanic students were the most interested in research opportunities, also pursued such experiences, and held positive attitudes about a research identity and career. The "leaky pipeline" for Hispanic American STEM majors may be due in part to their first generation college student status.

Most of our Hispanic and Black American STEM majors were the first generation in their families to attend college. We know from the interaction effects that these minority students are committed and ambitious. However, first generation students overall felt less informed about undergraduate research activities and less often participated.

They more often majored in engineering or computational sciences where undergraduate research opportunities may be less plentiful, and they have smaller social networks resulting from research activities.

First generation students take longer to complete a degree, perhaps because many must work their way through school; time and financial pressures may prevent them from learning more about research opportunities that could interest them—even at exactly the same university as continuing generation students. Because their parents were not college-educated, they may lack prior knowledge about opportunities that could provide not only more career clarification but also a more marketable competitive edge. This fusion of ethnicity and first generation status combine as a barrier that can hinder students from entering careers where they have an intellectual interest and could impede their career progress if they do enter research.

Undergraduate research offices, advisors and other personnel should make special efforts to bring research opportunities to the attention of first generation college students. By doing so, they will also encourage at least some African American and Latino/a students to take fuller advantage of college opportunities and help increase the number of STEM graduates. Coupled with other research evidence about campus engagement, these actions may increase first generation student integration into the college campus and thus support them in their educational persistence to achieve a degree.

We also found significant differences by type of STEM major. In particular, physical and life science majors felt the most knowledgeable and interested in undergraduate research opportunities. A research identity was the most central to them and they more often committed time and energy to research activities. Physical science majors had the largest research-related social networks, and the most positive research career attitudes and plans. Conversely, computational science majors were the least interested, least often participated in undergraduate research, had the lowest centrality of a research identity, and had the smallest research social networks. Certainly there are areas in computational science where undergraduates could engage in research. For example, computer simulations and *Monte Carlo* methods in several computational fields could interest these majors, as could research on critical thinking in mathematics and statistics. Perhaps faculty in these areas do not think of undergraduates as possible junior colleagues, or their efforts are not well-enough publicized to attract students.

## LIMITATIONS

This is, of course, one relatively self-selected group of college undergraduates from a southeastern public university. Without further research, we don't know how much our results will generalize.

The undergraduate experience is a prime time to construct an occupational identity and to test activities consistent with that identity that can simultaneously provide marketable knowledge and skills. We initially anticipated that in the early twenty-first century, we would see considerable diversity among students in exploring and engaging in research opportunities and constructing identities that, at least for some, would encourage a research career. However, what we found instead were areas of first generation student "neglect", which may depress Black or Hispanic American entrants into STEM fields as researchers. It is our hope that colleges and universities will provide more outreach and support to increase awareness and participation in the wealth of research opportunities available for undergraduates.

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# Discovering Infinite Number of Independent Balanced Forms of Some Typical Chemical Equations

**Pramode Ranjan Bhattacharjee**
*Kabi Nazrul Mahavidyalaya, Sonamura | West Tripura, Pin – 799 131, India*
*(E-mail: drpramode@rediffmail.com)*

**Abstract:** This paper reports on a novel idea falling within the purview of chemical science and engineering. It deals with a novel procedure for the algebraic method of balancing chemical reaction equations. The basic principle and relevant procedure of the novel scheme are offered along with illustrative examples. The fact that the balanced form of a chemical equation is not always unique is illustrated by the novel procedure offered in the paper. It has been found from the present study that, for each of the chemical equations (not involving ions) with $\{(m + n) - s\} > 1$, and for each of those involving ions with $\{(m + n) - s\} > 2$, where m = total number of reactants, n = total number of products, and s = total number of different kinds of elements on each side of the chemical equation, there exists an infinite number of independent balanced forms for each of those typical chemical equations.

**Key Words:** Chemical reaction; Chemical equation; Balancing of chemical equation.

## INTRODUCTION

Chemical equations are widely used in theory and practice. It is well known that the elements and compounds are expressed by their symbols and formulae, respectively. The chemists have devised a shorthand method to represent a chemical reaction symbolically, instead of in words. Such a shorthand method of representation of a chemical reaction with the help of symbols and formulae is called a *chemical equation*. If both the qualitative, as well as the quantitative, aspects of the reaction are reflected by a chemical equation, the equation is said to be a *true*, or *correct*, or *balanced chemical equation*. On the other hand, if a chemical equation only reflects the qualitative aspect of the chemical reaction, the equation is said to be an *unbalanced chemical equation*. A balanced chemical equation also helps in forming a mental picture in regard to the physical nature and properties of the reactants (viz., colour, state, etc.), as well as the chemical result and its physical nature. Balancing of chemical equations is an essential part of chemical mathematics called Stoichiometry, that is concerned with the mass and mole relationships determined by chemical equations and formulae. For these reasons, writing down a chemical equation correctly has drawn much attention in Chemical Education Research [1,13]. Chemistry students ought to be well conversant in writing and balancing chemical equations. The balancing of chemical equations is also an excellent exercise from demonstrative as well as pedagogical points of view.

This paper concentrates on the algebraic method of balancing chemical equations. The usual procedure of balancing chemical equations in the algebraic method is based on the fundamental principles of conservation of mass and charge. According to the principle of conservation of mass, the quantity of each element must remain the same on both sides in a chemical reaction. Thus, the same quantity of each element must appear on both sides of the true or balanced chemical equation. Also, from the principle of conservation of charge, the charge must be conserved in a chemical reaction. So, the same charge must remain present on both sides of the balanced chemical equation. Balanced equations are to be written with the smallest integer coefficients. If the coefficient is 1, it is understood.

The underlying principle as well as the procedure of the algebraic method of balancing chemical equation has been explained first in a novel way, considering a few examples. After applying this procedure to typical chemical equations, it is possible to generate an infinite number of independent balanced forms for each of those chemical equations without inviting any kind of ambiguity.

Thus, the present work enhancing the efficiency of the algebraic method of balancing chemical equations deserves special attention to the scientific and engineering community.

## BASIC PRINCIPLES INVOLVED IN THE ALGEBRAIC METHOD OF BALANCING CHEMICAL EQUATIONS

Let us consider the chemical equation:

$$R_1 + R_2 + R_3 + \ldots + R_m \rightarrow P_1 + P_2 + P_3 + \ldots + P_n \ \ldots (1)$$

with "m" number of reactants and "n" number of products. Let the number of different kinds of elements on each side of this chemical equation be "s". The balanced form of this chemical equation may be written as:

$$(c_1) R_1 + (c_2) R_2 + (c_3) R_3 + \ \ldots \ + (c_m) R_m$$

$$\rightarrow (C_{m+1})P_1 + (C_{m+2})P_2 + (C_{m+3})P_3 + \ldots + (C_{m+n})P_n \ldots (2)$$

where the (m + n) coefficients $c_1, c_2, c_3, \ \ldots \ , c_m, c_{m+1}, c_{m+2}, c_{m+3}, \ldots , c_{m+n}$ are smallest possible positive integers.

Since equation (2) is a balanced form of the chemical equation, the total number of each kind of the "s" number of elements on both sides of equation (2) must be equal. Equating the total number of each kind of "s" elements on both sides of equation (2), it would then be possible to write down a total of "s" linear equations involving the coefficients $c_1, c_2, c_3, \ldots , c_m, c_{m+1}, c_{m+2}, c_{m+3}, \ldots , c_{m+n}$.

It may now be noted that each of the aforesaid "s' number of equations will remain unchanged if both sides of each of those "s" number of equations are multiplied by μ (where μ is a constant or a positive integer or a non-negative proper fraction). Thus the aforesaid "s" equations will then be changed to "s" number of other linear equations involving the coefficients $x_1, x_2, x_3, \ldots , x_m, x_{m+1}, x_{m+2}, x_{m+3}, \ldots , x_{m+n}$, where $x_1 = \mu c_1$, $x_2 = \mu c_2$, $x_3 = \mu c_3, \ldots$, $x_m = \mu c_m$, $x_{m+1} = \mu_{m+1}$, $x_{m+2} = \mu_{m+2}$, $x_{m+3} = \mu_{m+3}, \ldots$, $x_{m+n} = \mu_{m+n}$.

It may further be noted that:

$x_1 : x_2 : x_3 : \ldots : x_m : x_{m+1} : x_{m+2} : x_{m+3} : \ldots : x_{m+n}$
$= c_1 : c_2 : c_3 : \ldots : c_m : c_{m+1} : c_{m+2} : c_{m+3} : \ldots : c_{m+n}$,
where $c_1, c_2, c_3, \ldots , c_m, c_{m+1}, c_{m+2}, c_{m+3}, \ldots , c_{m+n}$ are smallest possible positive integers.

Thus, to find the balanced form of a chemical equation of the type represented by equation (1) above, we should consider the "s" number of linear equations involving the (m + n) coefficients, $x_1, x_2, x_3, \ldots, x_m, x_{m+1}, x_{m+2}, x_{m+3}, \ldots , x_{m+n}$, where $x_i = \mu c_i$, $i \ \varepsilon \{1, 2, 3, \ldots , m, m + 1, m + 2, m + 3, \ldots , m + n\}$.

Those "s" number of equations are to be employed to ultimately find the ratio $x_1 : x_2 : x_3 : \ldots : x_m : x_{m+1} : x_{m+2} : x_{m+3} : \ldots : x_{m+n}$ in the simplest possible positive integer form, $c_1 : c_2 : c_3 : \ldots : c_m : c_{m+1} : c_{m+2} : c_{m+3} : \ldots : c_{m+n}$, with a view to identifying the required coefficients, $c_1, c_2, c_3, \ldots , c_m, c_{m+1}, c_{m+2}, c_{m+3}, \ldots , c_{m+n}$, with the help of which the balanced form(s) of the chemical equation under consideration could be easily written.

If the chemical equation under consideration contains ions, one more linear equation that will result from the conservation of charge is to be considered. In such a case there will be in all (s +1) equations involving the coefficients $x_i$ s, where $x_i = \mu c_i$, $i \ \varepsilon \{1, 2, 3, \ldots , m, m + 1, m + 2, m + 3, \ldots , m + n\}$. Those (s +1) equations will then be considered as above to pick out the required coefficients, $c_1, c_2, c_3, \ldots , c_m, c_{m+1}, c_{m+2}, c_{m+3}, \ldots , c_{m+n}$, in order to write down the balanced form(s) of such a chemical equation.

## THE NOVEL GENERAL PROCEDURE OF BALANCING CHEMICAL EQUATIONS BY ALGEBRAIC METHOD

The novel general procedure of balancing chemical reaction equation by algebraic method to be considered in this paper is based on the principle of conservation of mass as well as the principle of conservation of charge like the traditional schemes. The procedure of balancing a chemical equation in the novel approach is based on the following steps.

**Step 1:** Write the chemical reaction equation using the coefficients $x_i$ s, where $i \ \varepsilon \{1, 2, 3, 4, 5, 6, 7, \ldots , m + n\}$, "m" and "n" being respectively the total number of reactants and that of the products of the relevant chemical reaction.

**Step 2:** Form a set of "s" linear equations involving the coefficients $x_i$ s by equating the total number of element of each kind on both sides of the chemical equation, where "s" is the total number of different kinds of elements on each side of the chemical equation under consideration.

**Step 3:** If charged molecules or/and ions remain present in the chemical equation, form the (s + 1)th linear equation involving the coefficients $x_i$ s by equating the total charge on both sides of the chemical reaction equation.

**Step 4:** Consider all the equations formed in Step 2 and Step 3.

**Step 5:** By choosing any one of the coefficients $x_i$ to be equal to $k_1$, where $k_1$ is a positive integer or a non-negative proper fraction, see whether it is possible to express all other remaining coefficients $x_i$ s in terms of $k_1$. If so, continue on to Step 6. Otherwise, go to Step 8.

**Step 6:** Express the ratio $x_1 : x_2 : x_3 : \dots : x_{m+n}$ in the simplest possible positive integer form $c_1 : c_2 : c_3 : \dots : c_{m+n}$, and identify the corresponding values of the coefficients $c_i$ s , i $\varepsilon$ { 1, 2, 3, … , m + n }.

**Step 7:** Use the values of the coefficients, $c_1$, $c_2$, $c_3$, … , $c_{m+n}$ obtained in Step 6 to write down the only one balanced form of the relevant chemical equation.

**Step 8:** If by choosing the value of a particular coefficient $x_i$ to be equal to $k_1$, where $k_1$ is a positive integer or a non-negative proper fraction, it is not possible to express all other remaining coefficients $x_i$ s in terms of $k_1$, choose a second coefficient $x_i$ to be equal to $k_2$, where $k_2$ is a positive integer or a non-negative proper fraction, and see whether the remaining (m + n − 2) coefficients xi s can be expressed in terms of $k_1$ and $k_2$. If so, continue on to Step 9. Otherwise, go to Step 13.

**Step 9:** Remembering that each of $k_1$ and $k_2$ may be a positive integer or a non-negative proper fraction, assign any one of such pair of values to $k_1$ and $k_2$ out of the infinite number of choices and find the values of all the coefficients $x_i$ s, i $\varepsilon$ { 1, 2, 3, … , m + n }.

**Step 10:** Express the ratio $x_1 : x_2 : x_3 : \dots : x_{m+n}$ in the simplest possible positive integer form, $c_1 : c_2 : c_3 : \dots : c_{m+n}$, and identify the corresponding values of the coefficients $c_i$ s, i $\varepsilon$ { 1, 2, 3, … , m + n }.

**Step 11:** Use the values of the coefficients, $c_1$, $c_2$, $c_3$, … , $c_{m+n}$ obtained in Step 10 to write down one balanced form of the relevant chemical equation for the particular choice of the values of $k_1$ and $k_2$ as made in Step 9.

**Step 12:** Repeat Step 9 to Step 11 for each and every other pair of values of $k_1$ and $k_2$ out of an infinite number of choices to derive the corresponding other independent balanced forms of the chemical equation under consideration.

**Step 13:** Repeat Step 8 to Step 12 by choosing a third, fourth, fifth, etc. coefficients $x_i$ s respectively as $k_3$, $k_4$, $k_5$, etc., where $k_i$ is a positive integer or a non-negative proper fraction, i $\varepsilon$ { 3, 4, 5, … , m + n }, to obtain the infinite number of independent balanced forms of the chemical equation.

## APPLICATION OF THE NOVEL GENERAL PROCEDURE OF BALANCING CHEMICAL EQUATIONS BY ALGEBRAIC METHOD

In this section, the novel general procedure of balancing chemical equations by algebraic method will be employed to illustrate the said procedure by considering some examples.

***Example 1:*** Let us consider the balancing of the chemical equation:

$$NaNO_3 + Zn + NaOH \rightarrow Na_2ZnO_2 + NH_3 + H_2O$$

Let the balanced equation be:

$$(x_1)\,NaNO_3 + (x_2)\,Zn + (x_3)\,NaOH \rightarrow$$
$$(x_4)\,Na_2ZnO_2 + (x_5)\,NH_3 + (x_6)\,H_2O$$

where the coefficients $x_i$ s, i $\varepsilon$ { 1, 2, 3, 4, 5, 6 } are smallest positive integers.

Equating the number of atoms of each element on both sides of the above chemical equation we then obtain the following equations.

For Na: $x_1 + x_3 = 2x_4$ … (3)
For N: $x_1 = x_5$ … (4)
For O: $3x_1 + x_3 = 2x_4 + x_6$ … (5)
For Zn: $x_2 = x_4$ … (6)
For H: $x_3 = 3x_5 + 2x_6$ … (7)

Thus, we have five equations and the number of unknown integers to be found out is six. In order to evaluate the values of the six unknown positive integers in smallest form with the help of the aforesaid five equations, we now proceed as follows.

Let $x_1 = k$. Then from equation (4), we get, $x_5 = k$.

Hence from equations (3), (5), (6) and (7) we respectively get,

$-\ x_3 + 2x_4 = k$ … (8)
$-\ x_3 + 2x_4 + x_6 = 3k$ … (9)
$x_2 = x_4$ … (10)
and $-\ x_3 + 2x_6 = -\ 3k$ … (11)

Now, subtracting equation (9) from equation (8) we get, $x_6 = 2k$. Then from equation ( 11 ) we have, $x_3 = 7k$. Also from equation (8) we have then, $x_4 = 4k$ , and from equation (10), we have, $x_2 = 4k$.

Thus we obtain:

$x_1 = k, x_2 = 4k, x_3 = 7k, x_4 = 4k, x_5 = k, x_6 = 2k.$

Now, $x_1 : x_2 : x_3 : x_4 : x_5 : x_6 = 1 : 4 : 7 : 4 : 1 : 2.$

Hence the balanced form of the chemical equation is:

$NaNO_3 + 4Zn + 7NaOH \rightarrow 4Na_2ZnO_2 + NH_3 + 2H_2O$

***Example 2:*** Let us now consider the balancing of the following chemical equation:

$MgSO_4 + NaOH \rightarrow Mg(OH)_2 + Na_2SO_4$

Let the balanced equation be

$$(x_1)\, MgSO_4 + (x_2)\, NaOH \rightarrow (x_3)\, Mg(OH)_2 + (x_4)\, Na_2SO_4$$

Equating the number of atoms of same kind of element on both sides of the above chemical equation we then obtain the following equations.

For Mg: $x_1 = x_3$ … (12)
For S: $x_1 = x_4$ … (13)
For O: $4x_1 + x_2 = 2x_3 + 4x_4$ … (14)
For Na: $x_2 = 2x_4$ … (15)
For H: $x_2 = 2x_3$ … (16)

From equations (12), (13) and (15) we get:

$$x_1 = x_3 = x_4 = x_2/2 = k \text{ (say)}$$

Then $x_1 = k, x_2 = 2k, x_3 = k, x_4 = k.$

It can now be readily seen that both the equations (14) and (16) are satisfied with these values of $x_1$, $x_2$, $x_3$, and $x_4$.

Now, $x_1 : x_2 : x_3 : x_4 = 1 : 2 : 1 : 1.$

Hence, there is only one balanced form of the chemical equation under consideration and that is :

$$MgSO_4 + 2NaOH \rightarrow Mg(OH)_2 + Na_2SO_4$$

***Example 3:*** Let us consider the balancing of the chemical equation:

$$Cr_2O_7^{2-} + H^+ + Fe^{2+} \rightarrow Cr^{3+} + H_2O + Fe^{3+}$$

Let the balanced chemical equation be

$$(x_1)\, Cr_2O_7^{2-} + (x_2)\, H^+ + (x_3)\, Fe^{2+} \rightarrow (x_4)\, Cr^{3+} + (x_5)\, H_2O + (x_6)\, Fe^{3+}$$

Since the number of atoms of each kind on both sides must be equal, we have then the following equations:

For Fe: $x_3 = x_6$ … (17)
For H: $x_2 = 2x_5$ … (18)
For O: $x_1 = x_5/7$ … (19)
For Cr: $x_4 = 2x_1$ … (20)

Also, since the total charge before and after the reaction must remain the same, we must have,

$-2x_1 + x_2 + 2x_3 = 3x_4 + 3x_6$ … (21)

It is important to note that the equation (21) does not contain $x_5$. This is only because of the fact that water ($H_2O$) is neutral or zero-valent.

Using equations (17) and (18), we have from equation ( 21 ),

$-2x_1 + 2x_5 - x_6 = 3x_4$ … (22)

Now from equations (19) and (20) we get,

$$x_1 = x_4/2 = x_5/7 = k \text{ (say)}$$

Then $x_1 = k$, $x_4 = 2k$, and $x_5 = 7k$.

Hence we have from equation (22), $x_6 = 6k$. Also, from equations (17) and (18) we have then $x_3 = 6k$, and $x_2 = 14k$, respectively.

Now, $x_1 : x_2 : x_3 : x_4 : x_5 : x_6 = 1 : 14 : 6 : 2 : 7 : 6.$

Hence the balanced form of the chemical equation is:

$$Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$$

***Remark:*** It may be noted that the balanced form of each of the chemical equations considered in the above examples has been found to be unique. But this is not exactly so for the typical chemical equations (not involving ions) with $\{(m + n) - s\} > 1$ and for those involving ions with $\{(m + n) - s\} > 2$. In fact the same novel general procedure leads to infinite number of balanced forms of each such chemical equation, two examples of which are considered next.

***Example 4:*** Let us consider the balancing of the following chemical equation:

$P + HNO_3 + H_2O \rightarrow H_3PO_4 + NO + NO_2$

Let the balanced form of the above chemical equation be

$$( x_1) P + ( x_2 ) HNO_3 + ( x_3) H_2O \rightarrow ( x_4 ) H_3PO_4 + ( x_5 ) NO + ( x_6 ) NO_2$$

Since the number of atoms of each kind on both sides must be equal, we have then the following equations:

For P: $x_1 = x_4$ … (23)
For H: $x_2 + 2x_3 = 3x_4$ … (24)
For N: $x_2 = x_5 + x_6$ … (25)
For O: $3x_2 + x_3 = 4x_4 + x_5 + 2x_6$ … (26)

Now, let $x_1 = k_1$, so that from equation (23) we have, $x_4 = k_1$.

Then equation (24) reduces to

$x_2 + 2x_3 = 3k_1$ … (27)

Also, equation (26) becomes

$3x_2 + x_3 = 4k_1 + x_5 + 2x_6$ … (28)

Again let $x_2 = k_2$, so that from equation (27) we have $x_3 = ( 3k_1 - k_2 )/2$.

Equation (25) then becomes

$x_5 + x_6 = k_2$ … (29)

Also, equation (28) then becomes

$x_5 + 2x_6 = ( 5k_2 - 5k_1)/2$ … (30)

Now, solving for $x_5$ and $x_6$ we get from equations (29) and (30),
$x_5 = ( 5k_1 - k_2 )/2$, and $x_6 = ( 3k_2 - 5k_1 )/2$.

Thus we have

$x_1 = k_1, x_2 = k_2, x_3 = ( 3k_1 - k_2 )/2, x_4 = k_1,$
$x_5 = ( 5k_1 - k_2 )/2$, and $x_6 = ( 3k_2 - 5k_1 )/2$.

If $k_1 = 2$, and $k_2 = 5$, we have, $x_1 = 2$, $x_2 = 5$, $x_3 = 1/2$, $x_4 = 2$, $x_5 = 5/2$, and $x_6 = 5/2$.

Now, when reduced to simplest form we have, $x_1 : x_2 : x_3 : x_4 : x_5 : x_6 = 4 : 10 : 1 : 4 : 5 : 5$.

Thus, the balanced form of the chemical equation under consideration is :

$4P + 10HNO_3 + H_2O \rightarrow 4H_3PO_4 + 5NO + 5NO_2$

This is the only balanced form that exists in the traditional literature.

Again for a different choice such as $k_1 = 1$, and $k_2 = 2$, we have, $x_1 = 1$, $x_2 = 2$, $x_3 = 1/2$, $x_4 = 1$, $x_5 = 3/2$, and $x_6 = 1/2$.

Now, when reduced to simplest form we have, $x_1 : x_2 : x_3 : x_4 : x_5 : x_6 = 2 : 4 : 1 : 2 : 3 : 1$.

Thus, a second balanced form of the chemical equation under consideration is:

$2P + 4HNO_3 + H_2O \rightarrow 2H_3PO_4 + 3NO + NO_2$

Let us now proceed with the choice $k_1 = 5$, and $k_2 = 13$, so that we have, $x_1 = 5$, $x_2 = 13$, $x_3 = 1$, $x_4 = 5$, $x_5 = 6$, and $x_6 = 7$.

Now, when reduced to simplest form we have, $x_1 : x_2 : x_3 : x_4 : x_5 : x_6 = 5 : 13 : 1 : 5 : 6 : 7$.

Thus, a third balanced form of the chemical equation under consideration is:

$5P + 13HNO_3 + H_2O \rightarrow 5H_3PO_4 + 6NO + 7NO_2$

Proceeding in this way it is possible to obtain infinite number of independent balanced forms of the aforesaid chemical equation for all different choices of the values of $k_1$ and $k_2$.

***Example 5:*** Let us consider balancing of the following chemical equation:

$$KMnO_4 + H_2SO_4 + H_2O_2 \rightarrow MnSO_4 + K_2SO_4 + H_2O + O_2$$

Let the balanced form be

$$( x_1 ) KMnO_4 + ( x_2 ) H_2SO_4 + ( x_3 ) H_2O_2 \rightarrow ( x_4 ) MnSO_4 + ( x_5 ) K_2SO_4 + ( x_6 ) H_2O + ( x_7 ) O_2$$

Equating the number of atoms of each kind of element on both sides of the above chemical equation, we then obtain the following equations.

For K: $x_1 = 2x_5$ … (31)
For Mn: $x_1 = x_4$ … (32)
For O: $4x_1 + 4x_2 + 2x_3 = 4x_4 + 4x_5 + x_6 + 2x_7$ … (33)
For H: $x_2 + x_3 = x_6$ … (34)
For S: $x_2 = x_4 + x_5$ … (35)

Now let $x_1 = k_1$, so that from equations (31) and (32) we respectively have, $x_5 = k_1/2$, and $x_4 = k_1$.

Then from equation (35), we also have, $x_2 = 3k_1/2$.

Again let $x_3 = k_2$, so that from equation (34), we have, $x_6 = (3k_1 + 2k_2)/2$ and from equation (33), we have $x_7 = (5k_1 + 2k_2)/4$.

Thus we have

$$x_1 = k_1, x_2 = 3k_1/2, x_3 = k_2, x_4 = k_1, x_5 = k_1/2,$$
$$x_6 = (3k_1 + 2k_2)/2, \text{ and } x_7 = (5k_1 + 2k_2)/4.$$

As before, corresponding to a particular choice of the values of $k_1$ and $k_2$, it would be possible to get a particular balanced form of the relevant chemical equation.

For example, if $k_1 = 2$, and $k_2 = 5$, we have, $x_1 = 2$, $x_2 = 3$, $x_3 = 5$, $x_4 = 2$, $x_5 = 1$, $x_6 = 8$, and $x_7 = 5$.

When reduced to simplest form we have, $x_1 : x_2 : x_3 : x_4 : x_5 : x_6 : x_7 = 2 : 3 : 5 : 2 : 1 : 8 : 5$.

Thus, the balanced form of the chemical equation under consideration is:

$$2KMnO_4 + 3H_2SO_4 + 5H_2O_2 \rightarrow 2MnSO_4 + K_2SO_4 + 8H_2O + 5O_2$$

This is the only balanced form of the chemical equation that exists in the traditional literature.

Again if $k_1 = 2$, and $k_2 = 1$, then it can be readily seen that, we have in this case,

$$x_1 : x_2 : x_3 : x_4 : x_5 : x_6 : x_7 = 2 : 3 : 1 : 2 : 1 : 4 : 3$$

Thus, the second balanced form of the above chemical equation is :

$$2KMnO_4 + 3H_2SO_4 + H_2O_2 \rightarrow 2MnSO_4 + K_2SO_4 + 4H_2O + 3O_2$$

Now, if $k_1 = 2$, and $k_2 = 3$, then it can be readily seen that, we have in this case,

$$x_1 : x_2 : x_3 : x_4 : x_5 : x_6 : x_7 = 2 : 3 : 3 : 2 : 1 : 6 : 4$$

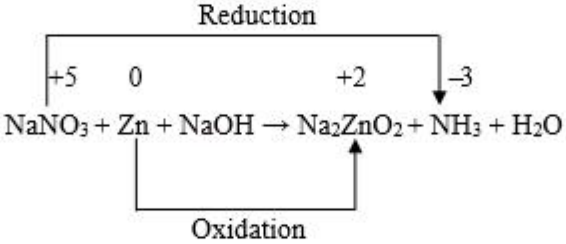
Thus, the third balanced form of the above chemical equation is :

$$2KMnO_4 + 3H_2SO_4 + 3H_2O_2 \rightarrow 2MnSO_4 + K_2SO_4 + 6H_2O + 4O_2$$

In a similar manner, by choosing arbitrary pair of values for $k_1$ and $k_2$, it would be possible to generate infinite number of independent balanced forms of the chemical equation under consideration.

However, where multiple options for a balanced equation are possible, it is important to recognize that equalizing the numbers of electrons transferred is determinative on the stoichiometric coefficients in the least complex final balancing. For this purpose the balancing of chemical equations by the "Oxidation number method" is now being considered below with reference to the chemical equations considered in Examples 1, 3, 4, and 5 above.

For the first chemical equation, viz., $NaNO_3 + Zn + NaOH \rightarrow Na_2ZnO_2 + NH_3 + H_2O$, the skeleton equation that includes those reactants and products containing the elements that suffer a change in oxidation numbers is as follows:



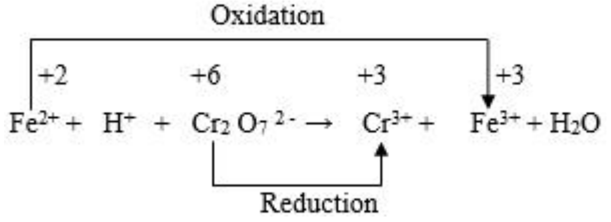
Looking at this skeleton equation we find that the oxidation number of Zn increases by (+ 2 − 0) or 2 and the oxidation number of N atom decreases by {(+ 5) − (− 3 )} or 8.

Now, in order that the increase and decrease of oxidation number are equal, there is a need of 4 atoms of Zn and 1 atom of N. Thus, the aforesaid chemical equation may be written as follows:

$$NaNO_3 + 4Zn + NaOH \rightarrow 4Na_2ZnO_2 + NH_3 + H_2O.$$

It can now be readily seen that in order to get the salt $Na_2ZnO_2$ as a product, there is a final need of 7 molecules of NaOH. Thus, the balanced chemical equation is: $NaNO_3 + 4Zn + 7NaOH \rightarrow 4Na_2ZnO_2 + NH_3 + 2H_2O$.

For the third chemical equation, viz., $Cr_2O_7^{2-} + H^+ + Fe^{2+} \rightarrow Cr^{3+} + H_2O + Fe^{3+}$, the skeleton equation is as follows:



Looking at this skeleton equation we find that the oxidation number of Fe increases by {(+ 3) − (+ 2)} or 1. Again the oxidation number of one Cr atom decreases by {(+6) − (+3)} or 3. Hence, the total decrease in oxidation number of two Cr atoms = 2 × 3 = 6.

Now, in order to equalize the increase and decrease of oxidation number, we are to put 2 in front of $Cr^{3+}$, 6 in front of $Fe^{2+}$ and 6 in front of $Fe^{3+}$. Thus we obtain the following equation:

$$6Fe^{2+} + H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 6Fe^{3+} + H_2O$$

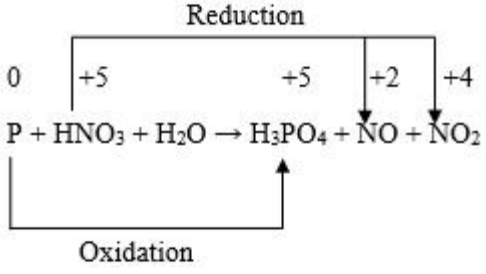
Now, in order to ensure that the number of O atoms on both sides are equal, the above equation will have to be changed to the following form:

$$6Fe^{2+} + H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O.$$

The balanced chemical equation can then be obtained by equalizing the number of H atoms on both sides as follows:

$$6\,Fe^{2+} + 14H^+ + Cr_2O_7^{2-} \rightarrow 2\,Cr^{3+} + 6Fe^{3+} + 7H_2O$$

For the fourth chemical equation, Viz. $P + HNO_3 + H_2O \rightarrow H_3PO_4 + NO + NO_2$, the skeleton equation is as follows:



Looking at this skeleton equation we find that the gain in oxidation number of P is {(+ 5) − 0} or 5.

Again the loss in oxidation number of N for the conversion:

(i) From $HNO_3 \rightarrow NO$ is {(+ 5) − (+ 2)} or 3,
(ii) From $HNO_3 \rightarrow NO_2$ is {(+ 5)− (+ 4)} or 1.

Thus, the net loss in oxidation number of N is (3 + 1) or 4.

Now, in order to equalize the gain and loss of oxidation number, we are to consider the following number of atoms and molecules of P and $HNO_3$ respectively.

(i) 4 atoms of P so that the total gain in oxidation number becomes (4 × 5) or 20

(ii) 5 molecules of $HNO_3$ for the conversion from $HNO_3 \rightarrow NO$, for which the decrease in oxidation number will be (5 × 3) or 15, the decrease in oxidation number for the conversion of one molecule of $HNO_3$ from $HNO_3 \rightarrow NO$ being equal to 3

(iii) 5 molecules of $HNO_3$ for the conversion from $HNO_3 \rightarrow NO_2$, for which the decrease in oxidation number will be (5 × 1) or 5, the decrease in oxidation number for the conversion of one molecule of $HNO_3$ from $HNO_3 \rightarrow NO_2$ being equal to 1

Thus, the overall loss in oxidation number will then be (15 + 5) or 20, which is exactly equal to the total gain in oxidation number.

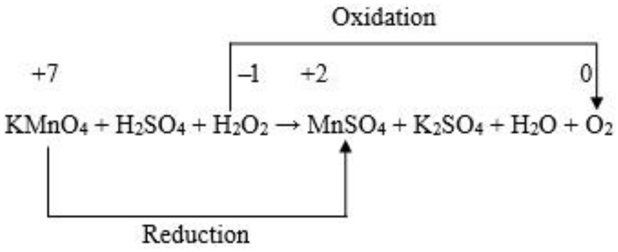
Thus, the chemical equation under consideration can then be written as:

$$4P + 5HNO_3 + 5HNO_3 + H_2O \rightarrow 4H_3PO_4 + NO + NO_2$$

The balanced chemical equation can then be obtained by equalizing the number of O atoms and N atoms on both sides as follows:

$$4P + 10HNO_3 + H_2O \rightarrow 4H_3PO_4 + 5NO + 5NO_2$$

For the fifth chemical equation, viz., $KMnO_4 + H_2SO_4 + H_2O_2 \rightarrow MnSO_4 + K_2SO_4 + H_2O + O_2$, the skeleton equation is as follows:



Looking at this skeleton equation we find that the oxidation number of one oxygen atom increases by $\{0 - (-1)\}$ or 1. Hence, the total increase in oxidation number for two oxygen atoms = $2 \times 1 = 2$. Again the oxidation number of one Mn atom decreases by $\{(+7) - (+2)\}$ or 5.

Now, in order to take care of the fact that the increase and decrease in oxidation number are equal, there is a need to consider 2 atoms of Mn and 10 atoms of oxygen. Thus the aforesaid chemical equation may be written as follows:

$$2KMnO_4 + H_2SO_4 + 5H_2O_2 \rightarrow$$
$$2MnSO_4 + K_2SO_4 + H_2O + 5O_2$$

Again, to get $K_2SO_4$ and $MnSO_4$ as products, there is a need to consider 3 molecules of $H_2SO_4$. This ultimately leads to the balanced equation as:

$$2KMnO_4 + 3H_2SO_4 + 5H_2O_2 \rightarrow$$
$$2MnSO_4 + K_2SO_4 + 8H_2O + 5O_2$$

This concludes the validity of the fact that equalizing the numbers of electrons transferred is determinative on the stoichiometric coefficients in the least complex final balancing.

## CONCLUSION

The procedure for the algebraic method of balancing chemical equation offered in this paper is novel. At the same time it also reflects the efficiency of the algebraic method in regard to generating multiple balanced forms for some typical chemical equations. The application of this novel procedure for balancing chemical equations leads to a satisfactory answer to the fundamental fact that, *the balanced form of a chemical equation is not always unique.* It is definitely unique (with lowest possible integral coefficients) so long as $\{(m + n) - s\} \leq 1$. In cases of chemical equations (not involving ions) with $\{(m + n) - s\} > 1$, and for those involving ions with $\{(m + n) - s\} > 2$, it is possible to generate infinite number of independent balanced forms of the chemical equation.

In view of all of the above, the author notes that the novel idea presented in this paper is not only mathematically interesting, but that it deserves attention from the academic and pedagogical points of view to the relevant fields of science and engineering.

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# THE STEM WORKFORCE: AN OCCUPATIONAL OVERVIEW

**Department of Professional Employees, AFL-CIO**
*Contact: Jennifer Dorning | DPE Research Department | Washington, DC 20006*
*(mail: jdorning@dpeaflcio.org)*

## Introduction

Professionals in science, technology, engineering, and mathematics (STEM) fields stand at the forefront of innovation in the U.S. economy. As technological changes reshape the world of work, these professionals are consistently in demand. However, some STEM occupations are struggling, especially in the natural and social sciences. This fact sheet will outline the employment and earning trends in STEM occupations; unionization in STEM fields; the location of STEM jobs; gender, race, and ethnicity in STEM; and the challenges offshoring and U.S. guest worker visa programs pose for U.S. STEM workers.

## Employment and Unemployment in STEM Occupations

In 2013, computer and mathematical occupations employed 3,816,000 workers, while there were 2,846,000 workers employed in architecture and engineering occupations and 1,316,000 in life, physical, and social science occupations. Together they accounted for 25.4 percent of the professional labor force and 5.6 percent of the total U.S. workforce [1].

Computer and mathematical-related occupations are driving growth among STEM occupations. From 2003 to 2013, computer and mathematical-related occupations

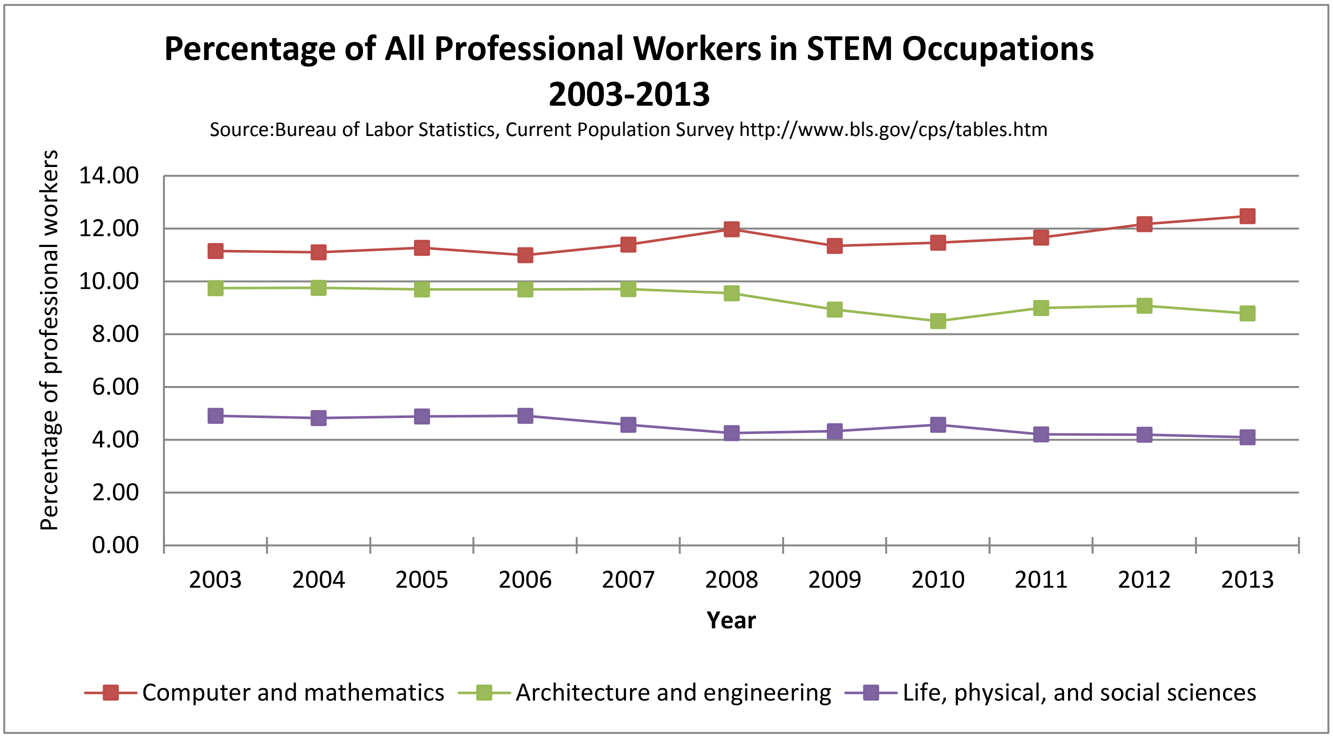
## About AFL-CIO (DPE)

*The Department for Professional Employees, AFL-CIO (DPE) comprises 22 AFL-CIO unions representing over four million people working in professional and technical occupations. DPE-affiliated unions represent: teachers, college professors, and school administrators; library workers; nurses, doctors, and other health care professionals; engineers, scientists, and IT workers; journalists and writers, broadcast technicians and communications specialists; performing and visual artists; professional athletes; professional firefighters; psychologists, social workers, and many others. DPE was chartered by the AFL-CIO in 1977 in recognition of the rapidly growing professional and technical occupations.*

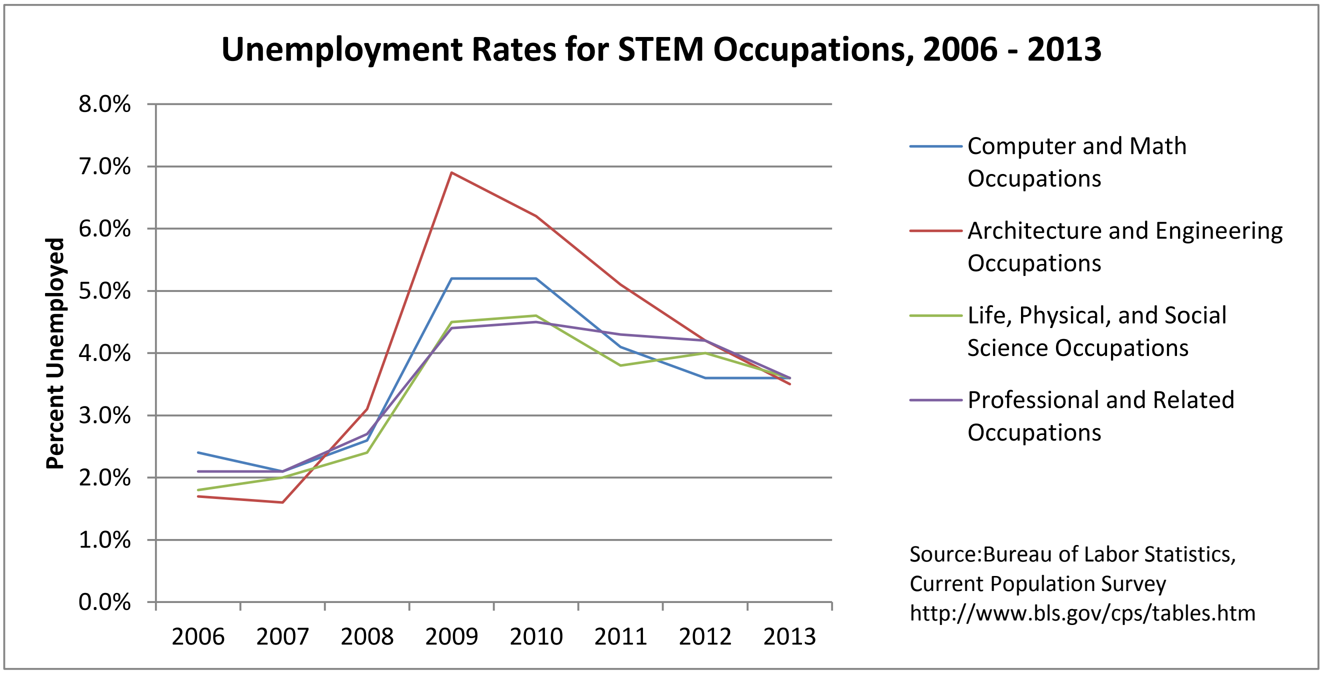
## Key Words

*STEM, Workforce, DPE.*

accounted for 98.7 percent of job growth in STEM occupations. From 2003 to 2013, architecture and engineering occupations added just 79,000 jobs and life, physical, and social science occupations lost 68,000 jobs [2]. At the same time, computer and mathematical occupations added 858,000 jobs.



Unemployment rates for STEM workers remains below the national average, but is in line with the unemployment rate for all professional and related workers [3]. As the chart below shows, STEM unemployment rates have not returned to their pre-recession levels.



Employment growth within the STEM field varies dramatically by occupation. From 2003-2013:

- Employment of computer programmers declined by 13.1 percent;
- Employment of aerospace engineers grew by 75.6 percent;
- Employment of electrical and electronics engineers decreased 17.4 percent;
- The number of drafters decreased by over 44 percent;
- Among the natural sciences, the number of biologists saw no change and chemists and materials scientists decreased 13.6 percent; and
- Medical scientists saw strong growth, increasing 42.6 percent and adding 43,000 jobs [4].

Recovery from the 2008 downturn started to take hold, in many STEM occupations, in 2010.

- Employment in professional and related occupations increased 3.6 percent from 2010 to 2013.
- Computer and mathematical occupations grew by 12.7 percent from 2010-2013. Nearly half of the growth was among mathematical occupations and computer support specialists.
- Architecture and engineering occupations added 187,000 jobs between 2010 and 2013, growing 7.1 percent. However, between 2008 and 2010, over 300,000 architecture and engineering jobs were shed.
- Life, physical, and social science occupations have clearly struggled to recover. Although the unemployment rate for life, physical, and social science occupations is similar to other STEM occupations, in the last four years these occupations have shed 102,000 jobs and total employment has declined by 7.2 percent [5].

## Mean Annual Earnings in 2012

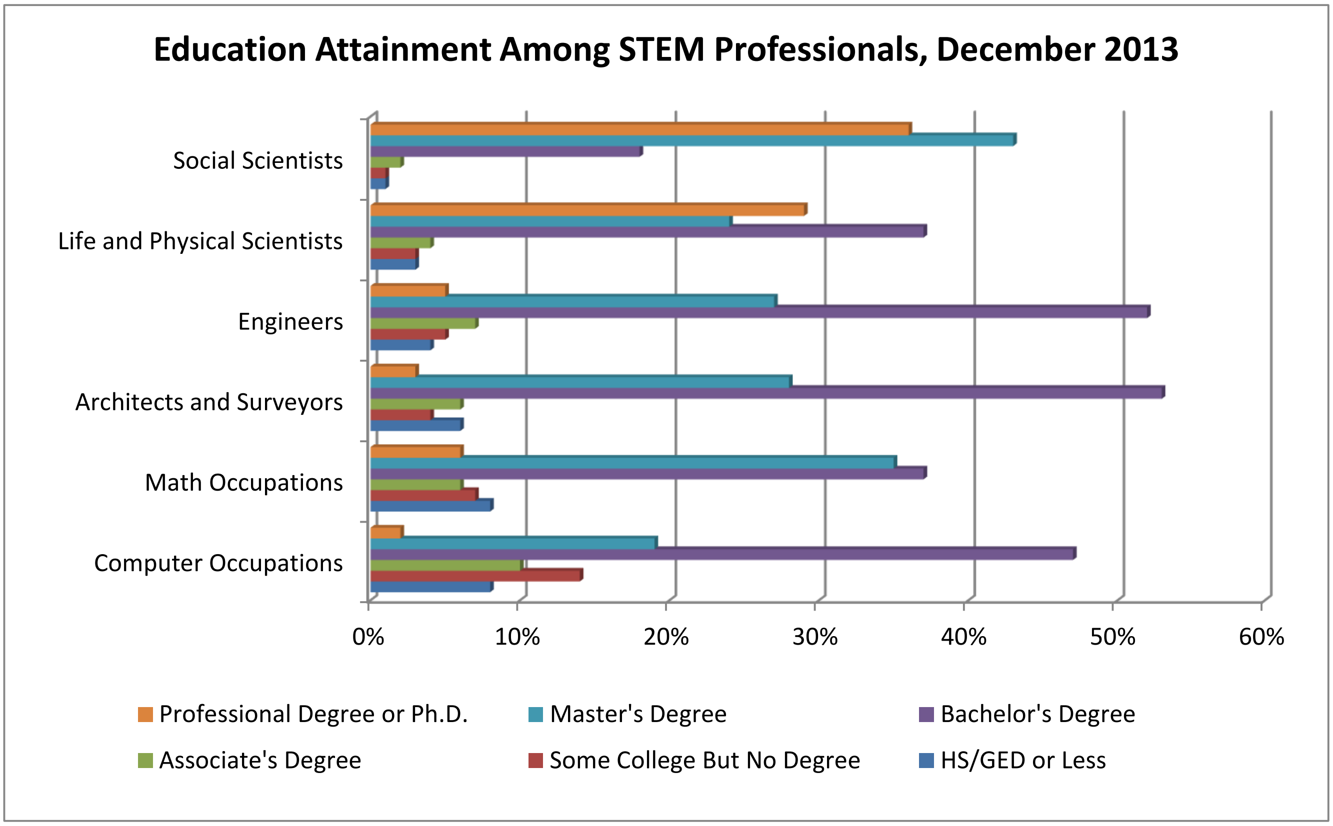
Professionals in STEM occupations typically have higher average salaries than other workers. A U.S. Department of Commerce study found that STEM jobs generally enjoy a wage premium over non-STEM jobs, reporting that those employed in the former earn 26 percent more than those employed in the latter. However, this premium diminishes when controlling for level of educational attainment [6].

Mean annual earnings in 2012 were generally higher for STEM jobs than other professional or related occupations; however, within each STEM field there was wide variation [7].

- In computer and mathematical jobs the mean annual wage was $80,180 in 2012; computer and information research scientists were at the top end of the wage range ($103,670) while computer support specialists earned a mean of $50,130 or $62,960 depending on the type of computer support provided (user or network).
- Mean annual earnings for engineers in 2012, ranged from $79,760 for industrial engineers at the low end of the pay scale to $147,470 for petroleum engineers at the high end of the pay scale. Engineering technicians earned a mean annual salary of between $49,220 for civil engineering technicians and $61,980 for aerospace engineering and operations technicians.
- Life, physical, and social scientists had the lowest mean annual earnings of the three STEM sectors ($68,360 in 2012). Generally, scientists earned more than the mean annual average (between $65,000 and $103,000). However, technician earnings were below average with agriculture and food science technicians earning just $36,390 in 2012 and nuclear technicians at the high end of the scale earning a mean annual wage of $69,720 in 2012 [8].

## Education Attainment

Education attainment in STEM occupations was high in December 2013. Among all STEM occupations, 72 percent of workers held a bachelor's degree or higher. Life, physical, and social scientists had the highest education attainment with 96 percent of social scientists and 91 percent of life and physical scientists having earned at least a bachelor's degree in December 2013 [9].



Education Attainment Among STEM Professionals, December 2013

In December 2013, among technical occupations, the education attainment was lower, which reflects the skills needed to perform the work. Most drafters and technicians had completed schooling beyond a high school diploma. Among drafters, 55 percent had completed an associate's degree in December 2013. Life, physical, and social science techs had high education attainment, with 52 percent having completed an associate's degree or higher in December 2013 [10].

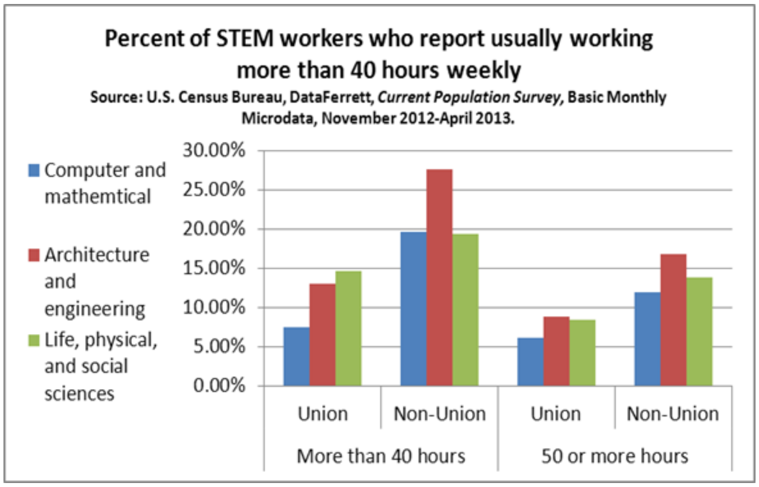
### *STEM Graduation Rates*

The supply of new STEM graduates is robust. In academic year 2011-12, 141,000 bachelor's degrees were conferred to graduates in natural sciences and mathematics and 146,000 bachelor's degrees were awarded to students in computer sciences and engineering. Also in academic year 2011-12, 26,000 master's degrees were awarded in natural sciences and mathematics and 66,000 degrees were awarded in computer sciences and engineering. Nearly 25,000 doctor's degrees were awarded to students in natural sciences, mathematics, computer sciences, and engineering in academic year 2011-12 [11].

## Union Membership and the Union Advantage

Union members generally have higher wages, better benefits, and more stable working conditions. In 2013, 16.7 percent of professional and related workers were members of unions [12]. STEM occupations generally had a lower rate of unionization.

- In 2013, 10 percent of professionals employed in life, physical, or social science related occupations were union members; 7.3 percent of professionals in architecture and engineering occupations were union members; and 4.3 percent of professionals in computer and mathematical occupation were union members [13].
- In 2013, psychologists (30.2 percent) and conservation scientists and foresters (23.3 percent) had the highest rate of union membership among those in life, physical, and social science occupations. Among engineers, environmental engineers (23.8 percent) and marine engineers (14.5 percent) reported the highest rates. In computer and mathematical fields, actuaries (11.1 percent) and operations research analysts (8.5 percent) had the highest rates of unionization [14].
- In 2012, unionization had a strong effect on wages for lower-paid STEM workers. Among engineering technicians other than drafters, unionized workers earned an average of $31.46 an hour, compared to an average hourly wage of $23.72 for non-unionized workers. Similarly, for computer support specialists, unionized workers earned $29.49 an hour compared to $25.79 an hour for non-unionized workers [15].
- Median weekly wages for full-time and salaried workers in life, physical, and social science fields were higher in 2013 for unionized ($1,233) than non-unionized ($1,149) employees 16].
- While computer and mathematical and architecture and engineering occupations generally report higher wages amongst non-union workers, there is evidence to suggest unionized workers enjoy an hourly premium. From November 2012 to April 2013, 12 percent of unionized workers reported they usually work more than 40 hours per week, compared to 19 percent for non-unionized STEM workers [17].



## Location Matters in STEM Employment

There are regional differences in the number of STEM field occupations available. In 2011, STEM jobs made up 5.2 percent of the total workforce nationwide. Across states, this ranged from a low of 2.8 percent in Mississippi to 10.1 percent in Washington, D.C. Population density and local industry influence the number and type of jobs available in a given area. Often, regions with federal research or contracting installations tend to have a larger number of people employed in STEM occupations [18].

- California has more than 13 percent of the U.S. STEM workforce (just over one million jobs). However, it lost 19,000 STEM jobs in the last decade (a 1.75 percent decline). Los Angeles County has the largest number of STEM jobs in the U.S. (more than 235,000).
- Washington, D.C. has more than two times the concentration of STEM jobs than the national average. Fairfax and Arlington counties —counties interconnected to D.C.'s economy— have helped Virginia expand its presence of STEM-related workers, on a per-capita basis, more than any other state in the last decade. Washington State, Seattle in particular, experienced the second fastest growth.
- The two counties in the U.S. with the most STEM workers per capita — Los Alamos, New Mexico, and Butte, Idaho — are home to major Department of Energy national laboratories [19].

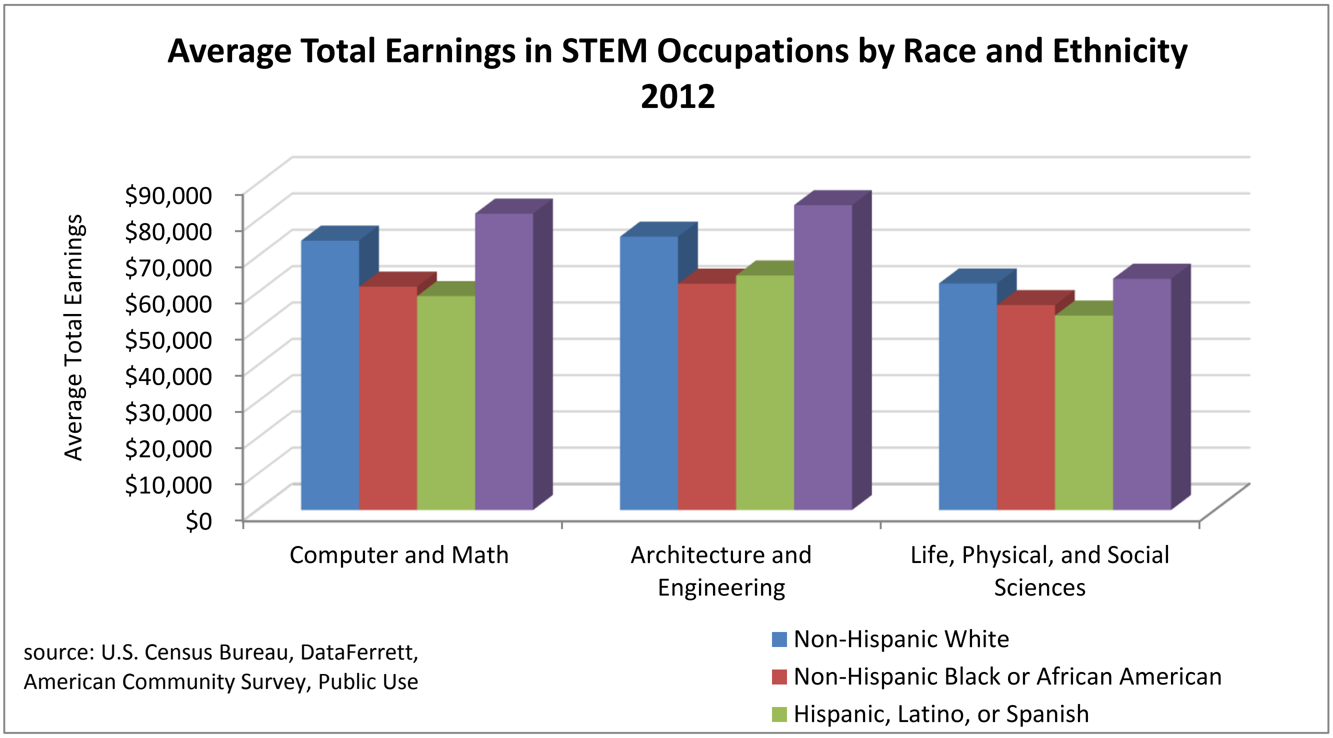
## Women, Black, and Hispanic Workers in STEM: Underpaid and Underrepresented

In STEM, there is under-representation of women and minorities; these workers are often concentrated in lower-paying technical occupations [20].

- While women made up 57.1 percent of all professional workers in 2013, they only comprised 46.1 percent of science professionals, 26.1 percent of computer and math professionals, and 14.1 percent of engineering and architecture professionals [21].
- Women's participation in computer and mathematics and life, physical, and social science occupations decreased from 2003–2013. However, women maintained the same concentration in architecture and engineering occupations from 2003 – 2013 [22].
- In 2013, medical and biological sciences represented women more proportionately than other STEM occupations where they were 52.4 percent and 52.7 percent, respectively, of all workers. However, they accounted for only 27.9 percent of environmental scientists. In psychology there was an over representation of women; almost three in four psychologists were women, yet median weekly earnings for women was $1,178 while the average for men and women was $1,267 (the average just for men was not available). Thus, male psychologists earned at least seven percent more than their female colleagues in 2013 [23].
- In every STEM occupation for which there is available data, the median weekly earnings for women were 11-25 percent lower than they were for men in 2012 [24].
- On average, men employed in professional and related occupations earned 27 percent more than women in 2013 [25].
- Black professionals represented 9.3 percent of the professional workforce and Hispanic professionals only 8.2 percent. Hispanic workers were 15.6 percent of the labor force in 2013 and Black workers comprised 11.2 percent of the labor force [26].
- In computer and mathematical occupations, 8.3 percent of workers were Black or African American, 6.3 were Hispanic or Latino, but 18.5 percent were Asian. Asians were just 8.3 percent of the professional workforce in 2013 [27].
- In the life, physical, and social sciences, Black professionals were under-represented, making up 5.6 percent of the workforce, and in architecture and engineering occupations, Black professionals were just 5.5 percent of the workforce in 2013 [28].
- Workers of Hispanic origin comprised 7.5 percent of the architecture and engineering field and 7.9 percent of life, physical, and social scientists [29].

- Black professionals were more proportionally represented in relatively lower-paying support or technician positions. They held 8.3 percent of engineering technician positions in 2013 and represented 13.2 percent of computer support personnel [30].
- Hispanic workers were also more proportionally represented in technician and technologist occupations, at 13 percent of engineering technicians and 10 percent of miscellaneous life, physical, and social science technicians in 2013. Among scientists, the highest proportion of Hispanics worked in chemistry and material science (12.3 percent) [31].

Asians reported the highest average earnings in each of the three STEM occupation sectors. Non-Hispanic Whites also had above average earnings, while Black and Hispanic or Latino professionals earned below average wages in 2012 [32].



source: U.S. Census Bureau, DataFerrett, American Community Survey, Public Use

When income data from technician occupations were removed from the earning averages, Black and Hispanic or Latino STEM professionals still earned thousands of dollars less than White and Asian STEM professionals in 2012 [33].

## Offshoring and Immigration Policy Challenges U.S. STEM Workers

The U.S. government makes available an array of skilled worker visas, including the H-1B, L, O, E3, and TN to employers seeking guest workers. In just FY 2012, nearly 470,000 guest worker visas were issued to employers for categories H-1B, L-1, optional practical training, O, TN (NAFTA professional), and E3 workers (Australian professionals) [34].

- Although skilled guest workers make up a very small percentage of the overall U.S. workforce, they are disproportionately concentrated in STEM industries. Among all STEM workers, 10.2 percent were not U.S. citizens in February 2014, (over 800,000 workers). In computer and mathematical occupations, 12.4 percent of workers were not citizens. In life, physical, and social science occupations, 10.4 percent were not U.S. citizens. Among architects and engineers, 6.8 percent of the workforce was not U.S. citizens [35].

- Tech industry lobbyists often claim that the visas make it possible to bring in the "best and brightest" workers to combat shortages of U.S. workers in STEM industries. Yet, there is no labor market test to ensure that unscrupulous employers do not replace U.S. professionals with temporary guest workers. According to the Alfred P. Sloan Foundation, "no one who has come to the question with an open mind has been able to find any objective data suggesting general 'shortages' of scientists and engineers." [36] Labor market indicators do not demonstrate a supply shortage and the evidence suggesting a need for more H-1B workers is anecdotal [37]. Further, as Harold Salzman of the Urban Institute points out, "the United States' education system produces a supply of qualified [science and engineering] graduates in much greater numbers than the jobs available." [38] Estimates indicate that close to 50 percent of STEM graduates in the U.S. are not hired in STEM-related fields, suggesting the claims of a shortage in STEM is largely rhetorical and not supported by the data [39].
- Despite the provisions stating that H-1B visa beneficiaries must receive the prevailing wage, guest workers generally make less than their U.S. counterparts. As far back as 2001, the National Research Council of the National Academy of Sciences and the National Academy of Engineering warned the "size of the H-1B workforce relative to the overall number of IT professionals is large enough to keep wages from rising as fast as might be expected in a tight labor market." [40] The Academy's warning bears true in current wage data.
  - From 2005 to 2012, the median hourly earnings for operations research analysts increased from \$32.84 to \$38.31. After adjusting for inflation this represents a one percent decrease in buying power [41].
  - Similarly, for computer programmers, the median hourly wage increased from \$30.49 in 2005 to \$35.71 in 2012, which, after adjusting for inflation, represents no increase in buying power [42].
  - A 2009 study from the Council on Foreign Relations shows that H-1B admissions at current levels are associated with about a five to six percent drop in wages for computer programmers and systems analysts [43].
  - In 2011, Georgetown University's Center on Education and the Workforce reported that engineering wages grew more slowly over the last three decades than any other occupational category, only 18 percent [44].
- The Department for Professional Employees, AFL-CIO supports comprehensive immigration reform to combat this trend, especially the creation of an independent commission that would ensure foreign and domestic workers fair access to jobs and protection from employer abuse. For more information on guest worker programs and professional and technical workers, see DPE's 2012 publication "Gaming the System" (http://dpeaflcio.org/wp-content/uploads/Gaming-the-System-2012-Revised.pdf). For more information on professional and technical workers, check DPE's website: www.dpeaflcio.org.

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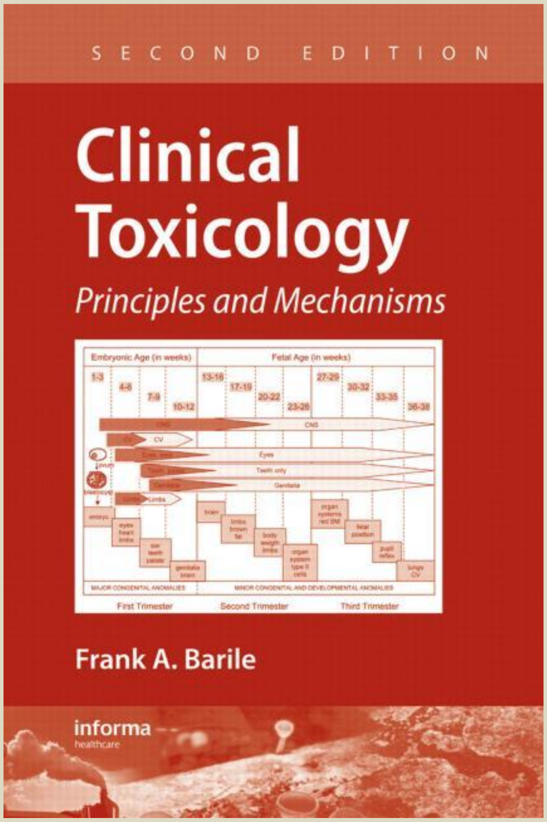
# Book Reviews

## Clinical Toxicology: Principles & Mechanisms. (2nd Edition)

**Reviewed by Dr. Margot Hall**
*University of Southern Mississippi, Hattiesburg, MS 39406*

This is a superior textbook for the clinical toxicologist and for undergraduate and beginning graduate students in the clinical sciences including pharmacology and clinical chemistry/clinical toxicology. The textbook covers some of the same topics commonly covered in other toxicology texts (e.g., mechanisms, toxicokinetics, medicinal chemistry), but it stresses certain topics not commonly seen in other toxicology textbooks (e.g., adverse drug reactions, signs and symptoms of toxicity, management of the toxic or overdose case, and the identification of toxicants in human body fluids). The text does not attempt to serve as a reference book for emergency medicine, but it does emphasize human pathology in the presence of human toxicity derived from therapeutic and street drugs, and other toxicants commonly seen in the hospital emergency room. Two chapters not always included in other texts offer information on chemical and biological terrorism and on herbal remedies. There is information on nuclear terrorism included in the chapter on radiation toxicity. A single author text, this book lists 5 additional contributors. It has 441 pages, numerous tables and figures, a table of contents, and an index. References (~10-30) are listed at the end of each chapter and are subdivided into books and journal articles. The book is divided into three parts:

1) introduction to basic toxicological principles,
2) toxicity of therapeutic agents, and
3) toxicity of non-therapeutic agents.



| | |
|---|---|
| **Authors:** | Frank A. Barile |
| **Publisher:** | CRC Press Lewis Publishers |
| **ISBN#:** | 1-4200-9225-1 |
| **Year:** | 2010 |
| **Price:** | $270.00 |

Part one has ten chapters including: 1) introduction and description of different areas of toxicology, 2) risk assessment and regulatory toxicology, 3) therapeutic monitoring of adverse drug reactions, 4) classification of toxins in humans, 5) exposure (routes of exposure, etc.), 6) effects (classification of effects and chemical interactions), 7) dose-response, 8) animal toxicity tests, 9) in vitro toxicity tests, and 10) toxic kinetics.

The second part of the book has eleven chapters covering the following classes of therapeutic agents: 1) sedative/hypnotics, 2) opioids and derivatives, 3) sympathomimetics, 4) hallucinogenic agents, 5) anticholinergic and neuroleptic drugs, 6) acetaminophen, salicylates, and nonsteroidal anti-inflammatory drugs, 7) steroids, 8) cardiovascular drugs, 9) antineoplastic drugs, 10) vitamins, and 11) herbal remedies.

The third part consists of 11 chapters on non-therapeutic toxicants including: 1) alcohols and aldehydes, 2) gases, 3) metals, 4) aliphatic and aromatic hydrocarbons, 5) insecticides, 6) herbicides, 7) rodenticides, 8) chemical carcinogenesis and mutagenesis, 9) reproductive and developmental toxicity, 10) radiation toxicity, and 11) chemical and biological threats to public safety.

One very nice feature of this book is the use of a clearly defined chapter outline with numerical as well as verbal headings and subheadings. Each drug listed has both generic/chemical and proprietary names listed. Typical subtopics for each drug include: 1) source and medicinal chemistry, 2) occurrence, 3) chemical structure, 4) pharmacology and clinical use, 5) toxicokinetics, 6) signs and symptoms of acute and chronic toxicity, 7) clinical management of toxicity, 8) tolerance, addiction, and withdrawal.

This book is recommended for a course in clinical toxicology or as suggested reading for a course in pharmacology, clinical chemistry, or forensic toxicology. It is a must have for the clinical toxicology laboratory.

# The AIC Code of Ethics

*Approved by the AIC Board of Directors, April 29, 1983*

The profession of chemistry is increasingly important to the progress and the welfare of the community. The Chemist is frequently responsible for decisions affecting the lives and fortunes of others. To protect the public and maintain the honor of the profession, the American Institute of Chemists has established the following rules of conduct. It is the Duty of the Chemist:

1. To uphold the law; not to engage in illegal work nor cooperate with anyone so engaged;

2. To avoid associating or being identified with any enterprise of questionable character;

3. To be diligent in exposing and opposing such errors and frauds as the Chemist's special knowledge brings to light;

4. To sustain the institute and burdens of the community as a responsible citizen;

5. To work and act in a strict spirit of fairness to employers, clients, contractors, employees, and in a spirit of personal helpfulness and fraternity toward other members of the chemical profession;

6. To use only honorable means of competition for professional employment; to advertise only in a dignified and factual manner; to refrain from unfairly injuring, directly or indirectly, the professional reputation, prospects, or business of a fellow Chemist, or attempting to supplant a fellow chemist already selected for employment; to perform services for a client only at rates that fairly reflect costs of equipment, supplies, and overhead expenses as well as fair personal compensation;

7. To accept employment from more than one employer or client only when there is no conflict of interest; to accept commission or compensation in any form from more than one interested party only with the full knowledge and consent of all parties concerned;

8. To perform all professional work in a manner that merits full confidence and trust; to be conservative in estimates, reports, and testimony, especially if these are related to the promotion of a business enterprise or the protection of the public interest, and to state explicitly any known bias embodied therein; to advise client or employer of the probability of success before undertaking a project;

9. To review the professional work of other chemists, when requested, fairly and in confidence, whether they are:
   a. subordinates or employees
   b. authors of proposals for grants or contracts
   c. authors of technical papers, patents, or other publications
   d. involved in litigation;

10. To advance the profession by exchanging general information and experience with fellow Chemists and by contributing to the work of technical societies and to the technical press when such contribution does

not conflict with the interests of a client or employer; to announce inventions and scientific advances first in this way rather than through the public press; to ensure that credit for technical work is given to its actual authors;

11. To work for any client or employer under a clear agreement, preferable in writing, as to the ownership of data, plans, improvements, inventions, designs, or other intellectual property developed or discovered while so employed, understanding that in the absence of a written agreement:
    a. results based on information from the client or employer, not obtainable elsewhere, are the property of the client or employer
    b. results based on knowledge or information belonging to the Chemist, or publicly available, are the property of the Chemist, the client or employer being entitled to their use only in the case or project for which the Chemist was retained
    c. all work and results outside of the field for which the Chemist was retained or employed, and not using time or facilities belonging to a client or employer, are the property of the Chemist;

12. Special data or information provided by a client or employer, or created by the Chemist and belonging to the client or employer, must be treated as confidential, used only in general as a part of the Chemist's professional experience, and published only after release by the client or employer;

13. To report any infractions of these principles of professional conduct to the authorities responsible for enforcement of applicable laws or regulations, or to the Ethics Committee of The American Institute of Chemists, as appropriate.

The Chemist
Journal of the American Institute of Chemists

# Manuscript Style Guide

***The Chemist*** is the official online refereed journal of The American Institute of Chemists (AIC). We accept submissions from all fields of chemistry defined broadly (e.g., scientific, educational, socio-political). *The Chemist* will not consider any paper or part of a paper that has been published or is under consideration for publication anywhere else. The editorial office of *The Chemist* is located at: The American Institute of Chemists, Inc. 315 Chestnut Street Philadelphia, PA 19106-2702, Email: aicoffice@theaic.org.

## Categories of Submissions

### RESEARCH PAPERS

Research Papers (up to ~5000 words) that are original will only be accepted. Research Papers are peer-reviewed and include an abstract, an introduction, up to 5 figures or tables, sections with brief subheadings and a maximum of approximately 30 references.

### REPORTS

Reports (up to ~3000 words) present new research results of broad interest to the chemistry community. Reports are peer- reviewed and include an abstract, an introductory paragraph, up to 3 figures or tables, and a maximum of approximately 15 references.

### BRIEF REPORTS

Brief Reports (up to ~1500 words) are short papers that are peer-reviewed and present novel techniques or results of interest to the chemistry community.

### REVIEW ARTICLES

Review Articles (up to ~6000 words) describe new or existing areas of interest to the chemistry community. Review Articles are peer-reviewed and include an abstract, an introduction that outlines the main point, brief subheadings for each section and up to 80 references.

### LETTERS

Letters (up to ~500 words) discuss material published in The Chemist in the last 8 months or issues of general interest to the chemistry community.

### BOOK REVIEWS

Book Reviews (up to ~ 500 words) will be accepted.

# Manuscript Preparation

## RESEARCH PAPERS, REPORTS, BRIEF REPORTS & REVIEW ARTICLES

- **The first page** should contain the title, authors and their respective institutions/affiliations and the corresponding author. The general area of chemistry the article represents should also be indicated, i.e. General Chemistry, Organic Chemistry, Physical Chemistry, Chemical Education, etc.

- **Titles** should be 55 characters or less for Research Papers, Reports, and Brief Reports. Review articles should have a title of up to 80 characters.

- **Abstracts** explain to the reader why the research was conducted and why it is important to the field. The abstract should be 100-150 words and convey the main point of the paper along with an outline of the results and conclusions.

- **Text** should start with a brief introduction highlighting the paper's significance and should be understood to readers of all chemistry disciplines. All symbols, abbreviations, and acronyms should be defined the first time they are used. All tables and figures should be cited in numerical order.

- **Units** must be used appropriately. Internationally accepted units of measurement should be used in conjunction with their numerical values. Abbreviate the units as shown: cal, kcal, µg, mg, g (or gm), %, ºC, nm, µm (not m), mm, cm, $cm^3$, m, in. (or write out inch), h (or hr), min, s (or sec), ml [write out liter(s)], kg. Wherever commonly used units are used their conversion factors must be shown at their first occurrence. Greek symbols are permitted as long as they show clearly in the soft copy.

- **References and notes** should be numbered in the order in which they are cited, starting with the text and then through the table and figure legends. Each reference should have a unique number and any references to unpublished data should be given a number in the text and referred to in the references. References should follow the standards presented in the AIC Reference Style Guidelines below.

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References should be cited as numbers within square brackets [] at the appropriate place in the text. The reference numbers should be cited in the correct order throughout the text (including those in tables and figure captions, numbered according to where the table or figure is designated to appear). The references themselves are listed in numerical order at the end of the final printed text along with any Notes. Journal abbreviations should be consistent with those presented in Chemical Abstracts Service Source Index (CASSI) (http://www.cas.org) guide available at most academic libraries.

- **Names** and initials of all authors should always be given in the reference and must not be replaced by the phrase *et al*. This does not preclude one from referring to them by the first author, et al in the text.

- **Tables** should be in numerical order as they appear in the text and they should not duplicate the text. Tables should be completely understandable without reading the text. Every table should have a title. Table titles should be placed above the respective tables.

  Table 1. Bond Lengths (Å) of 2-aminophenol

- **Figure legends** should be in numerical order as they appear in the text. Legends should be limited to 250 words.

  Figure 1. PVC Melt Flow Characterized by Analytical Structural Method

- **Letters and Book Reviews** should be clearly indicated as such when being submitted. They are not peer-reviewed and are published as submitted. Legends should be placed after/under the respective figures.

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  Booth DE, Isenhour TL. *The Chemist*, 2000, 77(6), 7-14.

- **Books -** For example:

  Turner GK in *Chemiluminescence: Applications*, ed. Knox Van Dyke, CRC Press, Boca Raton, 1985, vol 1, ch. 3, pp 43-78.

- **Patents** should be indicated in the following form:

  McCapra F, Tutt D, Topping RM, UK Patent Number 1 461 877, 1973.

- **Reports and bulletins, etc. -** For example:

  Smith AB, Jones CD, *Environmental Impact Report for the US*, final report to the National Science Foundation on Grant AAA-999999, Any University, Philadelphia, PA, 2006.

- **Material presented at meetings -** For example:

  Smith AB. Presented at the Pittsburgh Conference, Atlantic City, NJ, March 1983, paper 101.

- **Theses -** For example:

  Jones AB, Ph.D. Thesis, Columbia University, 2004.

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