ON THE FIRST LAW OF THERMODYNAMICS AND THE CONTRIBUTION OF JULIUS ROBERT MAYER: NEW TRANSLATION AND CONSIDERATION OF A REJECTED MANUSCRIPT

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Introduction

The first law of thermodynamics is a cornerstone of the chemical sciences. Its investigation in the nineteenth century augured and helped propel the industrial revolution. The core idea is elementary: regardless of the process and composition of a system and surroundings, energy is conserved at every instant. In simplest terms,

$$\Delta E_{\text{total}} = \Delta E_{\text{system}} + \Delta E_{\text{surroundings}} = 0$$

This is an exact law of nature—hence the equal signs in the above and with zero violations. A particularly insightful discussion of the first law has been presented by Denbigh (1).

It is a truism that nature's laws are established via experiments conducted by trained scientists. Thus in the nineteenth century, several individuals—Joule, Helmholtz, Thompson (Rumford), and Colding—focused on energy transformations in new quantitative depth and breadth. Yet truisms meet exceptions: the non-scientist Julius Robert Mayer is recognized *along with* the luminaries for proposing the first law concepts. Mayer's life and works have consequently warranted the scholarship of numerous science historians over the years. We call particular attention to the research of Caneva (2, 3), Gumpert (4), Steffens (5), Lindsay (6), and Truesdell (7). Four of these scholars have written monographs about Mayer. Truesdell has presented a captivating view of nineteenth century thermodynamics as a whole.

A person's professional oeuvre is embodied in publications, notebooks, and conference presentations. But there is another interesting, far-less-examined category, namely *rejected* manuscripts. These report advances that are regarded with confidence by their authors to be stand-alone contributions to a field. Editors and reviewers pronounce otherwise whereupon the manuscript must find another venue for dissemination. In some cases, the report languishes outright, rarely (if ever) to see the light of day.

J. R. Mayer's journey through thermodynamics includes the above scenario. His rejected paper "Über die quantitative and qualitative Bestimmung der Kräfte" presented a highly non-canonical probing of the first law in 1841. Mayer's viewpoint was not grounded upon apparatus, procedure, and data—tools of the scientific trade. Quite the contrary: he appealed to natural philosophy, the rudiments of which he acquired at a theological institute equivalent to modern-day high school. Mayer's professional training was in medicine and surgery and his university years in Tübingen did not allow time for philosophy. Yet his pre-medical grounding as a teenager included principles developed by Aristotle, Kant, and Schelling. Here forces are viewed as central to all phenomena. Matter is that which can be moved by forces and nature is indestructible by virtue of its forces. In effect, forces are primary.

Mayer's rejected handwritten manuscript was "rediscovered" in the *Poggendorff* Nachloss (i.e., that which remains in residual files) in 1877 and published in facsimile format by F. Zöllner in 1881 (8). The publication appeared three years after Mayer's death and forty years post submission of the manuscript to Poggendorf's *Annals of Physics and Chemistry*. While the original paper was lost in succeeding decades, the facsimile survives and has been discussed in several places (9). A transcription was published in a volume of Mayer's letters and other short works (10). A translation and brief commentary appear in Lindsay's book (6).

The present authors give renewed attention to Mayer's *first* albeit rejected work. We obtained a copy courtesy of the Stadt archives in Heilbronn, Germany. In so doing, we present an original, close translation of Mayer's words and focus on the philosophical and thermodynamic subtleties. We find the dismissed ideas to reflect several nuances of thermodynamics along with their universal scope. This was in spite of Mayer sidestepping manual labor and mathematical sophistication to bolster his arguments. It is just as clear that Mayer was writing independently of scientific ferment in the 1840s.

Mayer and Manuscripts—Accepted and Rejected

The majority of scholarship regarding Mayer has been initiated by his 1842 *accepted* paper: "Bermerkungen über die Kräfte der unbelebten Natur" (11). This is traditionally referred to as Mayer's *first* paper as it was indeed his inaugural publication. Joule, in his notebooks, included crude translations of this work and eyebrow-raising comments (penned in the margins) such as "Stupid! Does not everyone know this?" and "This is all old, and due to Davy and Rumford" (5). Some twenty years later, "Bermerkungen über die Kräfte" sparked a controversy. While presenting a lecture, Tyndall bestowed credit to *both* Mayer and Joule for establishing the first law of thermodynamics. Then over a several-year period, various parties responded to such sentiment with supporting arguments and denunciations, often acrimonious (7). All the while, Joule and Mayer *each* claimed priority of the first law discovery. Not incidentally, Helmholtz made references to Mayer as one of the founders of the principle of energy conservation. Helmholtz's 1854 lecture in Königsberg entitled "The Interaction of Natural Forces," specifically acknowledged Mayer's priority of discovery over Joule, Colding, and himself (12).

Obscured in the vitriol and occasional graciousness were Mayer's *first* words aimed at a journal audience. They are dated June 16, 1841, and were penned following Mayer's return from a sea voyage as ship's physician. A translation of the paper "On the Quantitative and Qualitative Aspect of Forces" follows (13). We have stayed as close as possible to the German lest we distort Mayer's intentions. In only a few places have we contemporized individual words and collective syntax. In particular, *Bestimmung* is most often translated as *determination*. We believe it best rendered as *aspect* or even *diagnosis* (14). Mayer was writing not just as an amateur philosopher, but also as a physician and surgeon.

The heading on the rejected manuscript is:

> Über die quantitative und qualitative Bestimmung der Kräfte
>
> Von J. R. Mayer, Dr. Med. & Chir., prakt. Arzt zu Heilbronn

This translates to "On the Quantitative and Qualitative Aspects of Forces." The author duly notes his occupation as a physician and surgeon in Heilbronn.

> The task of natural science is to relate the phenomena in the inanimate as well as the living world according to their causes and effects. All phenomena or processes are based on the fact that substances, objects, are changing the relationship in which they stand to one another. According to the law of the logical reasoning, we assume that nothing is happening without a cause, and one such cause we call force. We are getting to phenomena, following the causal connection upward, of which the causes are not accessible to our senses, but only can be abstracted from their effects, thus we call these forces, in the narrower sense, abstract forces.

This is Mayer's take on natural science. In the philosophy of Kant and Schelling, all knowledge must be justified (15, 16). The high style is consistent with the times.

> —All phenomena can be derived from one primordial force, which acts in the sense to cancel the existing differences, so that it combines all existence to one homogeneous mass in a mathematical point.

Mayer cites two notions in philosophical vogue in the nineteenth century. He reflects that there exists a force in the universe that is overriding. This force is the source of all—not just selected—phenomena. He follows this by declaring that the primordial force causes all systems to tend toward a most unusual state of equilibrium. By no means is Mayer speaking solely his own mind. Schelling viewed all in the world as unity arising from a single primordial source. All natural manifestations stem from the source and differ only by their particular mode of motion. In Schelling's (and apparently Mayer's) view, it is the *conflict* of forces that discloses the nature of chemical and physical phenomena (17).

> —Two objects, that are in a state of some definite difference, could remain in a state of rest after having cancelled that difference, if the forces imparted to them by the cancellation of the difference, could cease to exist; but, since these are deemed as being indestructible, thus they are still existing forces and act as causes of relationship changes that restore the continuance of a difference. Thus the principle that existing forces, just like matter, are quantitatively unchangeable ensures us conceptually of the continuance of the differences and with that of the material world. Both sciences, the one that concerns itself with the kind of existence of matter (Chemistry) as well as that which concerns itself with the kind of existence of forces (Physics), have to consider the quantity of their object as indestructible and only the quality of the same as changeable.

The last sentence is pivotal—that the *quantity* of an object is indestructible; only its *quality* can be altered. In no uncertain terms, Mayer is declaring that the mass and forces within a system are conserved. We note that by 1840, the works of Lavoisier on mass conservation had been well disseminated (18). Mayer was an astute reader of this literature prior to writing his thermodynamics papers (12).

> Two things, A and B, on whose relationship act change-producing forces, present principally the following situations: 1) they are either spatially separated, and then motion is the change of their relationship, or 2) they are not, and then changes in their relationship are related to chemical combination and separation and on special conditions, that occur at the contact of the bodies and produce electrical phenomena. At the moment, we speak only of the force that produces the change in the spatial relationships of the bodies, that is, of the moving force.
>
> If we place two objects in an isolated universe and impart a given difference to one another, both would move in a straight direction toward one another; the ultimate cause of the forces, or the cause, which manifests itself by the compensation of the existing difference, imparts to both bodies the moving force by whose consequence or appearance we see the motion occurring. The motion, which is existing at any moment, we determine quantitatively by the product of the mass times the velocity. Since the causes always relate themselves to the effects, thus the moving forces relate themselves to the motions, thus this product MC also will supply an exact contribution to the moving force V; consequently, we set $V = MC$.

Mayer uses V, M, and C to denote force, mass, and velocity, respectively. He quantifies the motion of a body as $V = MC$. Mayer apparently possessed fragmentary knowledge of motion laws.

> Since a given definite amount of $V = MC$ can be considered as determining the size of the movement, thus it is now a question of the determination of how this quantity of force expresses itself, or in how this motion proceeds, and this we define by the name *Quality* of motion. It includes
>
> (a) the energy of the motion or its relationship between its Intensity and Extensity. Important for quality is n in the expression $(M/n) \cdot nC$, in which n can express any whole and any fractional number,
>
> (b) provided we consider only diametrically opposed directions, the direction of the motion can be completely expressed by the simple signs + and –, in addition it is necessary to draw the projection by lines by whose length at the same time measure the quantity of the motion.

Mayer addresses the *quality* of motion. While he speaks imprecisely about energy, momentum, and forces, he sets the stage for assessing heat as motional in nature. Heat must have a quality that is fundamentally different from other forms of energy. Under heading (a), Mayer also discriminates intensive and extensive properties. This discrimination is a central facet of thermodynamics (19). Under heading (b), Mayer states the obvious: for motion in one dimension, the direction can be assessed simply via plus and minus signs. Mayer punctuates the idea via two diagrams in the manuscript. His "+" refers to rightward motion of a body; "–" applies to leftward motion. The lengths of straight lines allied with each type of motion scale with the magnitudes.

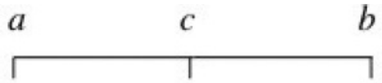
> Let's consider A and B, two objects, that are spatially separated and to which—disregarding gravitation—the moving forces v and v' are imparted; their respective velocities are c and c', thus $Ac = v$ and $Bc' = v'$, thus the quantity of the moving forces is invariably determined. Let $A = B$ and $v = v'$ and thus the total quantity of the moving forces is $Q = 2Ac$. —For the determination of the Quality of $2Ac$, we choose first of all the most simple case that A and B are moving in a direction straight toward one another; then $+Ac = -Bc$; the sign for the combined objects, A and B, is neither + nor –, but it is the sign 0, since A and B taken together will have neither motion toward one or the other; the movement $2Ac$ must thus proceed so that for every + motion there corresponds an equal motion in the opposed direction; therefore, these $2Ac$

> could neither become + nor –, but [it] they must be expressed by the sign 0; it is therefore clear, what is to be understood by the expression $0 \cdot 2Ac$; it is evident, that in no way is it synonymous with the numeral 0 and that the $2Ac$ package of force does not lose from its value by the prefaced qualitative sign 0; $2Ac$ is not decreasing in its amount owing to the previously set qualitative sign 0; $2Ac$ is the measure of the differentiation from the sign 0.

Mayer discards gravitational effects, as has become customary for thermodynamic systems. He focuses on the simple case of two objects possessing equal-magnitude, but opposite momenta. The result is that the combined scalar magnitude is *twice* that of either object motion taken individually. Mayer elects a roundabout way of saying that the vector sum of the motion quantities is zero. In Mayer's notation, the vector sum of the momenta is indicated by the "sign" zero. $2Ac$ represents the scalar sum of the vector magnitudes of the two objects in question. Curiously, Mayer constructs an ordered pair $(0, 2Ac)$ which he allies with a conserved quantity of motion. The confusion notwithstanding, emphasis should be placed on the insight that the "package of force does not lose from its value… ."

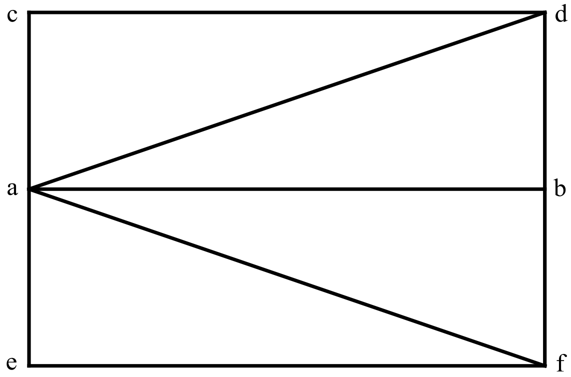
> For the determination of $0 \cdot 2Ac$ two opposing motions can suffice; however, it is possible for motions to occur from many, indeed from all directions; it is only necessary, that to each movement corresponds an opposing equivalent one; thus from the contact point of *A* and *B*, considered as a midpoint, all directional-radial, oscillating, wave form motions can occur. As far as the further qualitative determination of the energy of the movement is concerned, it depends, as mentioned, on the determination of *n* in $0(2A/n) \cdot nc$; the size of *n*, however, depends on the physical nature of the concerned object and its surroundings, and above all else on the efficiency of the substances for the moving force, i.e., the elasticity. In the case of perfect elasticity of *A* and *B*, then $n = 1$, $+Ac$ very simply is turned around into $-Ac$, $-Bc$ into $+Bc$: in the same measure when the elasticity is decreasing in respect to completeness, we see less movement generated, and in complete inelasticity, we see a complete cessation of motion: in the measure for inelasticity, by entirely stopping, we see less motion occurring and in the case of more complete inelasticity the motion discontinued entirely.
>
> A part of the moving force $2Ac$ or the total of the latter, under such circumstances actually are removed from observation; this quantity consisting of + and –, we call transformed.
>
> According to the assumption of the unchangeability of the quantity of forces, the quantity transformed is equal to the original motion occurring minus any force remaining; at complete inelasticity of *A* and *B* the transformed force is = $2Ac$.

Mayer considers collisions of objects and the contrast between elastic and inelastic ones. For inelastic, the magnitude of the combined momenta *decreases*, sometimes even to zero. Irrespective of the elasticity, the vector sum holds at zero. The second term in Mayer's ordered pair is influenced by the state of elasticity and so is varying from $2Ac$ to 0. Mayer recognizes that the difference must be accounted for—indeed transformed—into something else—perhaps heat, as we will see below. Of course, we know that the energy, not the scalar sum of momenta, is the quantity that is conserved. The mathematics of collisions was taken up in detail three decades later by Ludwig Boltzmann. Boltzmann includes brief commentary on Mayer's works in his *Lectures on Gas Theory* (20).



> —If we now describe the motion of *A* by *ac*, and that of *B* by an equal *bc*, thus *ab* becomes the measure of the transformed [force] = $2Ac$. The point *c*, that we call the null point, has its position in the middle, when it has been established by equally large opposed forces; it can, however, also be thought the zero point, so far as it is considered a fixed point, it could be situated at the end of the line. If a motion, *ab*, is brought to a stop at the fixed point *b*, again thus $ab = 2Ac$, the amount of the transformed [forces], so that the result in both cases is equal.
>
> The motions *ac* and *bc* can only then completely neutralize themselves when the angle $acb = 2R$. This result is in the same way less complete as the angle $acb < 2R$, In the case the angle $acb = 0$ the motion continues in its total value, thus the neutralized part becomes also = 0. If two motions meeting at an angle and combining themselves into a single motion, the direction of the value of the resulting motion will be given by the parallelogram of the forces; the neutralized part will thus become, as above indicated, the initially existing force minus the remaining, thus equal to the sum of the combined, minus the resulting. It is understood that the creation of a neutralized force presupposes the existence of real motion, thus no neutralized component is attributed to statics.

We have used the word "neutralize" to encapsulate "to make ineffective by an opposite force." Mayer does not define *R*; however, it clearly refers to a right angle. He does, however, include two diagrams, which are redrawn here.



> If we set in the parallelogram $abdc$, ad positive, then $ab + ac = ad$ + the neutralized motion, N, $ab + ae = af + N'$, or since $ae = –ac$, $ab – ac = af + N'$. By $ab – ac$ is obviously understood, that to the motion ab given magnitude and direction, is added another of the magnitude ac, but of the opposing direction; thus it is concluded that the contributors $ab + ac$ and $ab – ac$ give the same sum, thus will also $ad + N = af + N'$. If we would wish, however, instead of adding to ab the motion ae, we subtract from it ac which is equally large but of opposite direction, thus obviously the remainder will be smaller by $2ac$, or by ce, or by $0\ 2ac$ than the previous sum; if one will express this difference by zero, thus one obtains by subtraction of ac and by addition of ae exactly the same result; the same applies also for $ad – ac = ab + N''$. Without presenting further examples, we will only briefly indicate, that one of the usual applications of the parallelogram in dynamics always obtains results that are either too small or too large with respect to the neutralized motion. However, the results are completely correct concerning the kind and manner of the actual motion. The difference regarding the neutralized motion lies in the calculation then always equal to zero. As the case requires, opposite motion becomes zero, or, is allowed to proceed from zero, originating from opposite-direction motion.

Again, we recognize that the quantity Meyer treats is momentum rather than energy. In order to correctly add momenta, he must apply vector addition by the parallelogram law which leads to complications. The basis of his misconception is that for non-parallel vectors, vector addition *differs* from scalar addition. The magnitude of the resultant vector is always *less than* of the scalar sum of the magnitudes of the original vectors. The representation $0\ 2Ac$ is a combination of two different quantities. In the first position occupied by the 0 is a vector sum of the momenta of the moving objects. The position occupied by $2Ac$ is the sum of the scalar magnitudes of the momenta of the moving objects.

> Since indeed in our physical apparatuses forces can elude observation but, never can something be obtained which would be developed from zero, thus are likewise cases suited for experimentation in which the neutralized motion is left out, never, however, such, in which the formation of one has been proposed from zero; especially thus may ab and ac be combined to an ad, never, however, from an ad can two motions result, which have the magnitude of ab and ac, but they could be in any directions they wish.
>
> Let it be now permitted to us, from the above to deduce several conclusions for the natural science. —The neutralized $0\ 2MC$ is, in as much as the motion takes place not actually toward the opposing directions, the expression for heat. Motion, heat, and as we later intend to develop, electricity are phenomena which can be traced back to *some* force, and can be measured reciprocally and converted one to another according to definite laws. Motion converts into heat, by being neutralized by means of an opposing motion or by means of a fixed point, the heat produced is proportional to the motion that has disappeared. The heat on the other hand converts into motion in such a way that it expands the bodies; it causes, according to its general formula $0\ 2MC$, with $+MC$ or $–MC$, according to the particular case, opposing but all directional (radial) movement, the heated body itself remains at rest, therefore, it is designated the qualitative sign 0: A particular class, the transformation of simple motion to heat, creates the waves and the oscillating motions; in as much as they are radial, they are assigned the sign 0; in respect to heat they differ, however, in this way, so that with the latter, the motions keep their form of motion all the time; the magnitude of these motions can likewise also to be defined by $2MC$; based on differences in energies, they produce different results. In the formula, $(M/n)\ n\ C$, as given above, n, is the energy of the motion; if $n = \infty$ (at least close to ∞, may we be allowed to use this expression to make it short), thus we obtain the kind of motion, which portrays itself as light or as radiant heat. Light thus receives the movement: $(0\ 2\ M / \infty)\cdot(\infty\ C)$. Light forms heat when the motion converts to rest; from heat, light emerges when the accumulated neutralized motion again assumes the form of motion.

Mayer is overreaching by tying light, oscillations, and heat via simplistic reasoning—he uses symbols $(M/n)(nC)$ for light—perhaps for sound as well. Even so, he recognizes the universality of energy imbedded in nature's forces. In the 1840s, light was well known to travel at a great (albeit unmeasured) velocity and to carry no mass.

> If we connect an object, P, by an imaginary radius vector to a fixed point c, and produce through the P

> imparted motion *MC*, the peripheral motion, then *MC* splits into two motions, of which the first has the direction of the periphery, but the other, however, the direction –*Pc*; due to the fixed point *c*, the latter is constantly diminished, neutralized, thus one can see that *MC* imparted to *P* in *c* step by step becomes 0 *MC*, hence the motion of *P* thus is constantly decreasing. In the systems of the heavenly bodies gravitation represents the imaginary radius vector; instead of subtracting from the motion *MC* a motion in the direction –*Pc* there will be added one in the direction +*Pc* and through the forces, which are moving according to the combined laws of the statics and dynamics, are obtained not only the permanent movement of the celestial body *P*, but also by *c* for each revolution a measurable amount of motion neutralized. Expressed in another way it says this: in the same amount as the peripheral parts behave like they are falling to the center, the center falls toward the periphery.

Mayer abruptly takes up planetary motion. Because of his confusion with the "Neutralized," he had to invent a motion for his fixed point (due to gravity) in order to eliminate the "Neutralized." In Mayer's thinking, the planets are thereby able to revolve forever about the sun.

> In the star systems there is, therefore, a permanent development of a force, which for us is an insoluble problem, i.e., the changing of 0 to + *MC* – *MC* that has been solved by nature; the fruit thereof is the most wonderful part of the material world, the perpetual source of light,

In concluding remarks, Mayer mentions the eternal shining of the sun. He has no explanation of the source of the sun's energy. This problem regarding the sun's energy source had long troubled scientists and philosophers. Mayer reiterates the universality of energy and its transformative properties.

> * —To be continued.
>
> * The author puts forth the above principles, which in part form the basis of his concept of nature, intentionally in the shortest possible way. Truth requires for recognition not many words, and to desire to puff up errors as true is a vain attempt.

These words close the manuscript. Mayer indicates there is more to be said. His follow-up was a second manuscript that was accepted and published by *Liebig's Annalen* in 1842 (11).

Discussion

Early in his career, Julius Robert Mayer, although well educated, was not a member of the science community. By all accounts, he was confident in his abilities and openly sought recognition. These traits may have rendered him ill-suited to the Lutheran ministry, his original career path. Mayer instead became a physician, surgeon, and one-time ocean voyager. By his imagination and interests in fundamental concepts, he can be described as a creative thinker and *de facto* theoretician. It is noted that in late life, Mayer became sufficiently well known to share the podium at meetings with luminaries such as Helmholtz. Helmholtz was not alone in his acknowledgement of Mayer (6, 12). In particular, Mayer merited the praise of Tyndall which was to spark the controversy regarding the discovery of the first law of thermodynamics (7). The reader is directed to books by Lindley (21) and by Miller (22) for a clear-lens views of the priority controversy, in addition to the Mayer scholarship already cited (2-7). In effect, the star of Mayer's scientific reputation rose until his death in 1878, although he never lacked for critics. His life did not lack for tragedy as well: witness the death of children and attempted suicide. Curiously, Mayer is typically cited in the literature as *both* a physicist and physician. Thus, bearing in mind the philosophical content of his pre-medical studies, it is not surprising that he treated his early concept of forces from the perspective of a theorist rather than that of the physicist-experimentalist.

From a philosophic perspective, it is standard procedure to posit ideas in the absence of experimental proof. Mayer, in his rejected manuscript, buttressed a hypothesis concerning forces by the method of philosophic argument. In concept, he crafted an independent and, for significant parts, correct presentation. However, he undercut his efforts by a hurried and sketchy elaboration. In hindsight, we can see that he focused on the wrong measure of motion (momentum rather than energy), and incorrectly applied scalar and vector addition. Such errors may not surprise as vectors and scalars were scattered topics prior to Maxwell's contributions to electromagnetic theory (23). In addition, Mayer failed to appreciate the angular momentum of central force motion in his digression on planetary motion. Mayer's work was dismissed without comment by an established science journal. Yet we point out that he was neither alone nor the first to embrace science and philosophy simultaneously. Oersted in 1820 attributed electromagnetism properties to his metaphysical belief in the unity of all natural forces (24).

It should also be noted that Mayer committed several novice mistakes in publication strategy. He submitted a theoretical and speculative paper. He offered no experimental data and aimed at a medium distinguished for reports of rigorous experimentation and quantitative analysis. In addition, Mayer made the point to the editor that he (Mayer) considered the concept so crystal clear that he did not need to do much explaining. He purposefully wrote in a condensed style, the run-on sentences notwithstanding. He also assumed that the journal readership would find the mathematical treatments, diagrams, and physical significance wholly self-evident. Additionally, Mayer gratuitously informed the editor that only in papers that possibly were in error did the author need to use extensive discussion. Finally, he ended his paper with the terse comment "to be continued." Mayer had a favorable opinion of his thoughts put to paper.

But there is arguable reason for the opinion as debated over the years. Mayer recognized that he was treating a broad principle of nature, which cut across *both* the animate and the inanimate world. This was revolutionary in some respects as the animate (and especially human) world was widely thought to be exempt from inanimate-guiding principles. Moreover, he initiated discussion via a *model*—an elementary construct grounded upon an operational definition of natural science and, sentences later, motion in one dimension. Then Mayer asserted that all phenomena are derived from one primordial force which pushes all systems toward equilibrium. Next he pointed out that forces are held to be indestructible in accord with theological and philosophical foundations. After that, Mayer noted that the substance of chemistry (matter) was indestructible and that the substance of physics (force), just like matter, was also indestructible. As the lynchpin, he reckoned that the material world could be reasoned to be indestructible. This final observation completed the model. Mayer had arrived at the conservation laws for material and the *forces* behind *all* motion. We understand these entities today to underpin the first law of thermodynamics. Also, he gave a practical definition of heat in attempting to explain the conservation of motion and its transformation into heat. On this account, Mayer may be credited with helping to overthrow the Caloric theory of heat. His perspective was not experimental, but by *cause* and *effect* reasoning—*causa aequat effectum*. If a system contained and/or transferred heat, there *had* to have been causes underpinned by forces. This was non-conformist at the time. As of the early nineteenth century, heat was viewed as a *cause* of phenomena: it predicated fires, summertime discomfort, winter survival and so forth. Mayer contemplated matters in quite the opposite direction.

Mayer attempted to support his construction via mechanical examples. In each case, he developed an argument that momentum conservation was valid and indeed absolute. He ended his paper by positing that the orbital mechanics of the heavenly bodies adhered to his model; however, the light energy from the stars was insufficiently understood to allow interpretation. In concept, Mayer's support of his model by mechanics was sound. However, his shaky command of physics resulted in glaring errors. These diminished his credibility with science contemporaries and certainly with the journal editors. However, Mayer's problems with theoretical exposition on conservation principles in no way diminished the veracity of his central theme. Mayer uses the word *Energie* in his rejected manuscript in three places, although it is not evident that the word has the same meaning as it carries today. In his follow-up work appearing in *Liebig's Annalen*, the paper often credited for the concept of conservation of energy, he curiously does not write the word *Energie* anywhere.

Julius Robert Mayer was a creative thinker—and dedicated. During the voyage to the East Indies, he was overwhelmed by *his* recognition of the law of conserved forces. While in port, he declined the pleasures afforded by the shore and chose to remain on board the ship. Mayer was *that* obsessed with contemplation of a new concept. We close with Tyndall's appraisal of Mayer in an 1891 letter written to Jacob Johann Weyrauch (25):

> No greater genius than Robert Mayer has appeared in our century. Some men who now overshadow him will be undoubtedly placed beneath him in the future history of science.

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About the Authors

Bruno Jaselskis is Professor Emeritus of Chemistry at Loyola University Chicago. He was born in Lithuania. Following World War II, he worked in Germany for UNRRA—the United Nations Relief and Rehabilitation Administration—and the World YMCA. He immigrated to the United States in 1949 and proceeded to earn a B.S. degree in chemistry at Union College of Schenectady, New York. This was followed by work for the masters and doctoral chemistry degrees at Iowa State University. Professor Jaselskis subsequently joined the chemistry faculty as a lecturer at the University of Michigan. After five years, he moved to Chicago to become an Assistant Professor at Loyola University in 1962. Over the years, his research has focused on analytical chemistry, the chemistry of noble gases, and the historical development of the chemical sciences.

Carl E. Moore passed away in early 2012 as Emeritus Professor of Chemistry at Loyola University Chicago. He had been a Loyola faculty member since 1952. Professor Moore was born in Frankfort, Kentucky, and received a B.S. degree in chemistry from Eastern Kentucky State Teachers College in 1939. This was followed by an M.S. degree in chemistry from the University of Louisville in 1947. He matriculated at the Ohio State University following WWII and completed work for the doctoral chemistry degree in 1952. He joined the Loyola University faculty immediately thereafter. His research and teaching of six decades concentrated on analytical chemistry and the philosophy of science. During the 1970s, Professor Moore completed a six-year tour of duty as department chair at Loyola Chicago.

Alfred von Smolinski passed away in 2009; at the time he was Professor Emeritus. He was born in Cernauti, Romania, in 1919. He pursued chemistry studies for three years at the University of Cernauti. He then transferred to the University of Bucharest for his final undergraduate year and received the diploma in chemistry. In 1942, he moved to Germany and was employed in the chemical industry. In 1955 he immigrated to Chicago and received the M.S. and Ph.D. degrees from Loyola University Chicago. His research was supervised by Professor Carl E. Moore. Following the years at Loyola, Professor Smolinski taught chemistry at Youngstown State University and at the University of Illinois Chicago in the Department of Medicinal Chemistry.

Daniel J. Graham is Professor of Chemistry at Loyola University Chicago. He was born and raised in San Francisco, California. He completed a B.S. degree with honors at Stanford University in 1976. This was followed by doctoral studies in physical chemistry at Washington University, St. Louis. He carried out postdoctoral work in molecular spectroscopy at Boston University. This was followed by a chemistry faculty position at West Virginia University. Professor Graham moved to Chicago in 1987 to join the Chemistry Department of Loyola University. His research focuses on thermodynamics and information theory applied to organic compounds.

Albert Claus is Professor Emeritus of Physics at Loyola University Chicago. He was born and raised in Chicago and earned his undergraduate degree at Northwestern University in Evanston, Illinois. He proceeded to doctoral studies in physical chemistry at the California Institute of Technology in Pasadena, California. Professor Claus's graduate research in x-ray crystallography was supervised by Linus Pauling. Following his Pasadena years, Professor Claus became a chemistry faculty member at the University of Alaska in Anchorage, Alaska. After two years, he moved to Chicago and soon joined the Physics Department of Loyola University in 1962.

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