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Physics in Perspective

John Tyndall's Vertical Physics: From Rock Quarries to Icy Peaks

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I analyze, through the work of the Irish physicist John Tyndall (1820–1893), the close relationship formed in the mid-nineteenth century between advances in the physical sciences and the rise of mountaineering as a sport. Along with groundbreaking experimental research in the physical sciences, Tyndall worked throughout his career to define and popularize the study of physics. He also was a pioneering mountaineer during the golden age of mountaineering. As he practiced his science, from rock quarries to the study of the blue sky, Tyndall's interests in the fundamental forces of Nature brought him to the summits of mountains. His sojourns to the mountains, in turn, affected the manner in which he approached his researches. His science and mountaineering were tellingly mixed, and worked in unison to shape public perceptions of what physicists did during a period of increasing specialization and popularization of the field.

Key words: John Tyndall; Joseph Dalton Hooker; Thomas Henry Huxley; James David Forbes; Michael Faraday; Royal Institution of Great Britain; British Association for the Advancement of Science; Alps; mountaineering; physics; radiant heat; glaciers; popularization.

> They were no idle scamperers on the mountains that made these wild recesses first known; it was not the desire for health which now brings some, or the desire for grandeur and beauty which brings others, or the wish to be able to say that they have climbed a mountain or crossed a col, which I fear brings a good many more; it was a desire for *knowledge* that brought the first explorers here….
>
> John Tyndall (1872)[1]

Introduction: Verticality and Science

In the early morning hours of July 30, 1864, the renowned Irish physicist John Tyndall (1820–1893) found himself in the Swiss Alps tumbling headlong at incredible speeds down the back of an avalanche. Only moments earlier he had been static, clinging tightly to steps cut by his guide into the hardened ice of a

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glacier. In a mere instant, everything changed. He heard a peculiar rushing sound as his two climbing companions, their guide, and a jumbled mass of snow whirled over his left shoulder. A hemp rope bound him to the same fate. He and his guide were pulled immediately downward, caught in the avalanche's grip and carried mercilessly for over a thousand feet before he managed to plant his ice axe and arrest his own fall, mere seconds from an impending chasm and certain death. Incredibly, everyone walked away from the terrifying experience unscathed. Tyndall could find only portions of his watch chain, however, one piece dangling around his neck and another tucked safely into his pocket. The watch itself had vanished.[2]

Similar to most mountaineers who live through such near-death experiences, Tyndall focused little on the actual harm that could have befallen him. He simply hiked back to his chalet and ate a hardy meal. Yet, he could not get the missing watch out of his mind. He returned to the scene more than two weeks later, confident that his own research on the power of metals to absorb and radiate heat could help him recoup his loss. His watch was made of gold, and its slight absorbent power, Tyndall reasoned, would prevent it from sinking farther into the billowing snow left at the base of the avalanche. After only a short time searching, the watch appeared just as he had speculated. "It had remained eighteen days in the avalanche," Tyndall recounted years later, "but the application of its key at once restored it to action, and it has gone with unvarying regularity ever since."[3]

This was not the first time that Tyndall had placed himself in extreme danger on the vertical faces of mountains. Nor would it be the last time that he combined his mountaineering exploits with his knowledge of physics. In this instance, the mingling of science and extreme sport led merely to the recovery of his gold timepiece. At other times, I will suggest, the same combination resulted in major advances in physics, though the extreme and often dangerous manner in which Tyndall came to these advances have been largely forgotten. My aim is to resurrect the relationship between Tyndall's research programs in the physical sciences and his lifelong interest in mountaineering. I will demonstrate how Tyndall viewed his exploits in mountaineering as a way to harness a vertical laboratory of Nature, and how this vertical orientation, in turn, transformed the way he both approached his researches and defined the field of physics.

That scientific investigations helped spur the development of mountaineering is well known, often forming the introductory material for books published on the history of alpinism.[4] Less well known is the manner in which alpine climbing helped stimulate a new way of approaching questions in science. Moreover, past historical scholarship on Victorian "science in the field" has focused primarily on the natural historical sciences.[5] The history of natural history is replete with examples of how naturalists or their hired assistants searched the oceans and continents to formulate their taxonomies, build their theories, and explain the geographical distribution of species. This is no less true in the vertical realm. Joseph Dalton Hooker (1817–1911), for example, the premier British botanist in the Victorian era and one of the first champions of Darwin's theory of evolution through natural selection, explored the mountainous regions of Nepal and Tibet and attempted to scale Kinchinjunga, then thought to be the highest peak in the world. He traveled to the Himalaya, tellingly, to answer questions concerning the adaptation of species to different environments.[6] Traveling vertically up a mountain enabled Hooker to pass through several different vegetation zones, enabling him to detail the variations produced in species. Charles Darwin (1809–1882), in turn, used Hooker's observations, along with the botanical specimens he sent back to the Royal Botanical Gardens at Kew, to support his own theory of the transmutation of species.

Similarly, the science of geography has been deeply influenced by the mountaineering feats of some of its most energetic practitioners, from Horace Bénédict de Saussure (1740–1799), the first natural philosopher to reach the summit of Mont Blanc, to Halford John Mackinder (1861–1947), the premier definer of the modern discipline in Britain. Mackinder was the founder and Director of the first School of Geography in Britain (Oxford, 1899), but just as he was formulating its curriculum before the first term began, he dropped everything to lead the first successful attempt to reach the summit of Mt. Kenya,[7] the second-highest peak in Africa. He used the climb to help define the science of geography: He rested his reputation as a geographer on the climb and used his experiences to define the parameters and methods of this burgeoning field. Moreover, like Hooker before him, he approached his work through an explicit vertical orientation. In his journals and subsequent publications, he quite consciously made a transition in the narrative of his ascent from a horizontal plane (based on railroad mile markers) to a vertical one (based on base camps and altitude).

The history of natural history offers poignant examples of how a vertical orientation helped shape and advance specific scientific disciplines. Much less, however, has been written on the relationship between verticality and the physical sciences, though recent work has begun to investigate the role of high-altitude field stations in the advance of geophysics.[8] Fortunately, in the history of science there are a wealth of physical scientists who were influenced by the mountains, from Blaise Pascal (1623–1662) in the seventeenth century, to James David Forbes (1809–1868) in the nineteenth century, to Werner Heisenberg (1901–1976) in the twentieth century. I will use the work of John Tyndall not only to demonstrate the connection between his science and his alpinism, but also to establish the broader role of vertical geographies in advancing the physical sciences in the Victorian era. While climbing in the Alps, Tyndall realized that there were questions in physics that could only be answered through a vertical orientation. He consistently performed experiments and compared observations made at different heights, deliberately formulating his research programs based on his ability as an alpinist to climb vertically up the sides of mountains. As he described these researches to a broader public, through dramatic lectures at the Royal Institution of Great Britain and exhilarating mountaineering narratives, he helped define the field of physics in the Victorian era.

John Tyndall in History

John Tyndall (figure 1) is an important figure in the history of nineteenth-century science, contributing significant research in electricity, magnetism, radiant heat, the chemical molecular theory, and the constitution of the atmosphere. He is best known for his fieldwork in glaciology, where he argued against the "viscous theory" proposed earlier by James David Forbes.[9] He also undertook sophisticated laboratory experiments as part of his path-breaking research on radiant heat, demonstrating how "perfectly colorless and invisible gases and vapours" could absorb solar radiation.[10] He was the first researcher to verify experimentally that atmospheric gases, particularly water vapor and ozone, contributed significantly to the warming of the planet. His work on radiant heat at high altitudes also suggested his next several research topics, including the role of microbes in fermentation and the scattering of light by particles in the atmosphere. He received the Royal Society's prestigious Rumford Medal in 1869 for his varied accomplishments in science, the same year in which he helped found the journal *Nature*. He published prolifically throughout his career, including sixteen books and upwards of one hundred and fifty scientific articles.[11]

Despite his ambitious research programs and fundamental contributions to science, he has received far less attention than his contemporaries, such as the naturalist Thomas Henry Huxley (1825–1895) or the botanist Hooker, owing

Fig. 1. John Tyndall (1820-1893) in 1864. *Credit*: American Institute of Physics Emilio Segrè Visual Archives, Brittle Books Collection.

partly to the devastating circumstances surrounding his death. His wife accidentally poisoned him with an overdose of the medicine he had long taken to treat his insomnia. Extremely grieved, she demanded control of his correspondence and journals so that she could write an account of his life and popularize his work. Her failure to finish a biography had the adverse effect that Tyndall's personal correspondence lay unpublished and understudied until the appearance of A.S. Eve and C.H. Creasey's biography in 1945.* To the Victorians themselves, however, he was a giant among scientists, personally involved in most of the public controversies that impinged on the authority of science as it sought to gain inroads in Victorian culture.

Along with his close friends Hooker and Huxley, Tyndall defended science from its religious critics, arguing that naturalistic rather than theistic explanations could (and should) account for the workings of Nature. Along with his research in experimental physics, he is perhaps best known for his address to the British Association for the Advancement of Science in Belfast in 1874.[12] In his "Belfast Address," he irreverently argued that science "shall wrest from theology, the entire domain of cosmological theory," bringing post-Darwinian materialism in science to the forefront of polite society.[13] He was also part of the small but influential cadre of scientists who formed the X Club in 1864 to lobby for the public support of scientific research and to direct the path of science more generally.[14] He became Professor of Natural Philosophy at the Royal Institution of Great Britain in 1854, holding this position until his retirement in 1887. In this capacity, he perhaps accomplished more than anyone else in popularizing the amazing advances occurring in the physical sciences in the Victorian era, including the concepts of energy conservation, the chemical atomic theory, and the electromagnetic theory of light.[15] "Others will rank beside or above him as investigators," the editors of *Nature* proclaimed after his retirement from the Royal Institution, "but in the promotion of the great scientific movement of the last fifty years he has played a part second to none."[16] *The Scientific Monthly* concurred. He "reached a large audience," physicist Arthur Whitmore Smith (1874–1954) wrote in 1920, "and did more than any other person to secure the wide diffusion of these all-pervading truths that lie at the foundation of physical science."[17]

In many respects, therefore, Tyndall assumed a position in the physical sciences similar to that of Hooker and Huxley in the natural historical sciences. These three figures – Huxley, Hooker, and Tyndall – did more to define their respective fields of biology, botany, and physics than any other figures in the nineteenth century. Huxley, as Darwin's bulldog, was an evolutionist intent on spreading the gospel of

* Bernard Lightman at York University is currently spearheading the John Tyndall Correspondence Project, which includes twelve universities in four countries. The Project aims to publish a comprehensive one-volume calendar of correspondence and an eight-volume complete correspondence of John Tyndall. See the website <http://www.yorku.ca/tyndall>.

natural selection, but more importantly, he also was a scientist equally interested in advancing the role and authority of science within broader culture. Hooker, likewise, became an early defender of evolutionary theory, but only insofar as it helped give direction to his botanical research. As Director of the Royal Botanical Gardens at Kew, he used his position to influence the course and direction of botany by bounding its study and defining who could and could not participate in it.[18] Tyndall was interested in the physical rather than the natural historical sciences, but he too succeeded in advancing the field by both defining its boundaries and promoting its authority before fashionable middle-class audiences.

Like many of his contemporaries, Tyndall was many-sided: a practicing physicist, a world-renowned popularizer, and a self-fashioned definer of his field. Yet, he also was one of the premier mountaineers of his day, largely responsible for popularizing the sport in Britain during the golden age of mountaineering, usually denoted as the period between 1853 and 1865 when the Alps became the "playground" of Europe.[19] He narrowly missed being the first to reach the summit of the Matterhorn, then thought to be entirely inaccessible. He was the eighth person to do so but the first to climb the more difficult traverse up from Breuil and down to Zermatt. He also made numerous first ascents of other lesser peaks throughout the Alps, including the captivating Weisshorn in 1861. In the process, he significantly advanced the sport of mountaineering. In the era before pitons, carabiners, or sophisticated rope techniques, he pioneered the art of rock climbing – as opposed to ice and snow climbing – and was among the first to undertake guideless climbing. Mountaineers at this time were called "amateurs" because they were required to use professional guides, so Tyndall's guideless sojourns in the Alps represent a significant step toward the professionalization of mountaineering. He also was one of the first scientists to promote high-altitude field sites as important for scientific research. Historians, however, have yet to integrate Tyndall's professional goals as a physicist with his equally fascinating accomplishments as a mountaineer. As historian Roy MacLeod has noted, we lack a "comprehensive review of Tyndall's work on optical and crystalline structure; on magnetism, radiation, and mountaineering, as well as the relationships between his several 'research programmes'."[20] Viewing Tyndall's scientific work in conjunction with his alpine climbing will allow us to obtain an integrated view of his seemingly varied research programs in the physical sciences.

Tyndall provided a glimpse of what he thought about the relationship between his science and mountaineering in the Preface to his *Hours of Exercise in the Alps*, published in 1871, the same year in which he published his highly popular *Fragments of Science*:

> A short time ago I published a book of "Fragments," which might have been called "Hours of Exercise in the Attic and the Laboratory"; while this one bears the title of "Hours of Exercise in the Alps." The two volumes supplement each other, and, taken together, illustrate the mode in which a lover of natural knowledge and of natural scenery chooses to spend his life.

> Much as I enjoy the work, I do not think that I could have filled my days and hours in the Alps with clambering alone. The climbing in many cases was the peg on which a thousand other "exercises" were hung.[21]

By taking seriously the role of vertical space in Tyndall's scientific researches, we can more fully understand how he perilously hung these "thousand other 'exercises'" on the vertical cliffs in the Swiss Alps.

Tyndall's Research Programs

John Tyndall was born into poor circumstances in Ireland, and after years of rather unremarkable primary education, he entered the workforce as a civil assistant in the Irish Ordnance Survey.[22] He received training both in the field as a surveyor and at his desk in mathematics and drafting techniques. He worked stints at the firm of Nevins and Lawton as a railroad engineer, then on the West Riding Union Railway, and finally as a surveyor for the English Ordnance Survey.[23] The hours were long and the pay was low; when he justifiably complained, he was immediately fired. Then, in August 1847, on the advice of a family friend he took a job at the recently founded Queenwood College in Hampshire, England, teaching mathematics and surveying. Edward Frankland (1825–1899) was also on the faculty and responsible for teaching physics and chemistry. Tyndall audited all of Frankland's courses, and in October 1848 they set off together for the University of Marburg where Tyndall was deeply influenced by the lectures given by the renowned German chemist Robert Bunsen (1811–1899). Tyndall attained his doctorate in two years, returned to England to teach at Queenwood College, and in 1854 became one of the editors of the *Philosophical Magazine*, charged with translating articles in physics from their original German, including those of Rudolf Clausius (1822–1888) on the mechanical theory of heat.

Tyndall also began lecturing to broader audiences. In 1850, at a meeting of the British Association for the Advancement of Science in Edinburgh, Tyndall gave a talk on diamagnetism that contradicted some of the prevailing notions of the day, including those espoused by Michael Faraday (1791–1867). Later, in early 1853, Tyndall passed through London and for the first time heard Faraday lecture on the magnetic force at the Royal Institution. Soon thereafter, he himself was invited to give a lecture there on diamagnetism. As Tyndall's biographers noted, his Friday evening lecture on February 11, 1853, "took his audience by storm" and "decided Tyndall's fate."[24] In 1854, owing to his energetic lecturing style and commanding grasp of experimental techniques, he was offered the position of Professor of Natural Philosophy at the Royal Institution, a post he held for thirty-three years. From humble beginnings in Ireland, Tyndall had risen to hold one of the premier scientific positions in England.

Tyndall's training in surveying and work as a railway engineer led to his fascination with the magnetic properties of the earth's rocks, particularly the role of

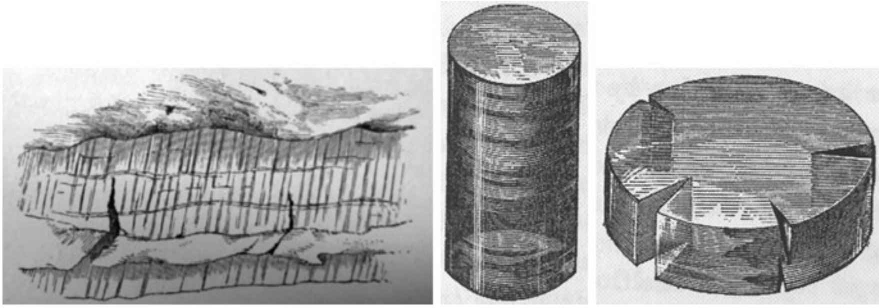

Fig. 2. (*Left*) The veined structure of the Aletsch Glacier with vertical crevasses. *Source*: Tyndall, *The Glaciers of the Alps* (ref. 26), p. 391. (*Right*) The similar veined structure of ice that Tyndall produced experimentally at the Royal Institution. *Source*: Tyndall, *Hours of Exercise* (ref. 2), p. 381.

pressure on crystalline structures. Slate was deposited through time in horizontal layers, but the cleavage planes were vertical, suggesting that they were produced at right angles to the pressure working on the slate. In 1854, he traveled to the slate quarries in the Snowdon region of Wales to gain firsthand knowledge of their cleavage planes, hopeful that direct analysis would reveal something about their molecular structure.[25] He then lectured on "slaty cleavage" at the Royal Institution in 1856. In the audience sat Thomas Henry Huxley, who suggested that the same mechanisms responsible for producing cleavage in slate might also be responsible for producing the veined structures of glaciers. From the mid-1850s, Tyndall visited the Swiss Alps every summer to conduct observations on glaciers, experiments he published in the *Philosophical Transactions of the Royal Society of London* in the late 1850s and collected in his epic *The Glaciers of the Alps* of 1860.[26] He also performed laboratory experiments on ice at the Royal Institution during the winter months. Through this combination of laboratory work and field work (figure 2), he came to view glaciers as "vast ice presses," arguing that crevasses were produced by the pressure built up in the body of the glacier, which then fractured and reformed through a process that he termed – at the suggestion of Joseph Dalton Hooker – "regelation."[27]

In 1856 Tyndall made his first tour of the Swiss Alps in the company of Huxley. He was not yet a mountaineer, and did not go much farther afield than to visit the makeshift laboratory of Louis Aggasiz (1807–1873), which the Swiss scientist had cobbled together on the Mer de Glace. "It is difficult, in words, to convey the force of the evidence which this glacier presents to the observer who *sees* it," Tyndall wrote of his first experiences on the crevassed ice fields. "[It] seems in fact like a grand laboratory experiment made by Nature herself...."[28] He returned to this "grand laboratory" every summer for the rest of his life, and with him he brought his own interest in defining the field of physics. "The natural sciences are in a sad mess in England," Tyndall wrote after his first full summer amongst the glaciers.

Fig. 3. Tyndall's ascent of the Lauwinen Thor in August 1860. He took to the rocks (upper middle), while his guides kept to the ice and snow. Note the barometer carried on the back of the third guide. *Source*: Tyndall, *Hours of Exercise* (ref. 2), facing p. 11.

"People appear to have no clear idea of what the region of Physics is. They mix it up with Chemistry, and in the present instance everything else is mixed up with them; and for all these sciences, thus taken *en masse*, we have the same figure as for a single one of the classical languages!"[29] As Tyndall continued to ponder his grand laboratory in the decades to come, he accomplished much in the way of clearing up this mix for future generations.

The following summer of 1857 Tyndall returned to the Alps without Huxley, intent on expanding his laboratory beyond the confines of glaciers to the actual peaks and passes throughout Switzerland. On his first mountaineering venture, up the Lauwnin Thor (figure 3), we see the kind of climber Tyndall was:

> Mr. Hawkins and the two guides then turned to the left, and regained the snow, leaving me among the crags. They had steps to cut, while I had none, and, consequently, I got rapidly above them. The work becomes ever harder, and rest is unattainable, for there is no resting-place. At every brow I pause; legs

> and breast are laid against the rough rock, so as to lessen by their friction the strain upon the arms, which are stretched to grasp some protuberance above. Thus I rest, and thus I learn that three days' training is not sufficient to dislodge London from one's lungs.[30]

Tyndall always stuck to the rocks when he could, rather than confining himself to the snow and ice as previous alpinists had done. Along with Edward Whymper (1840–1911) and Leslie Stephens (1832–1904), he thus pioneered a unique approach to climbing in the Victorian era.

That same summer, Tyndall also went through the initiation rite of all serious scientific mountaineers: the climbing of Mont Blanc. He set up five observation stations interspersed between the bottom and top of the massive mountain, requiring twenty-six porters to carry all of his instruments. At each station they measured how long it took candles to burn, they shot rockets into the air to see how their appearance differed from above and below, and they discharged pistols to study the effects of the differing atmospheres on sound. Verticality was taking hold on Tyndall's work. His research programs, including his intense study of glacier motion and experiments on light, heat, and sound, increasingly relied upon his ability to compare observations made at different heights. He spent about twenty hours on the top of Mont Blanc performing various experiments, and his account offers a glimpse at his other, perhaps more pressing interests.

> Though the main object of the expedition was to plant the posts and fix the thermometers, I was very anxious to make some observations on the transparency of the lower strata of the atmosphere to the solar heat-rays. I therefore arranged a series of observations with the Abbé Veuillet, of Chamouni [Chamonix]; he was to operate in the valley, while I observed at the top. Our instruments were of the same kind; in this way I hoped to determine the influence of the stratum of air interposed between the top and bottom of the mountain upon the solar radiation.[31]

Tyndall's work on glaciers and his fascination with mountaineering led him to engage the topic of radiant heat, particularly the manner in which gases absorb solar and heat radiation, a subject he would follow for the next decade of his life.[32] Indeed, as historian James Fleming has noted, it was out of his interests in mountaineering that he developed his lifelong interest in meteorological phenomenon.[33] In his mountaineering narratives, he never failed to discuss the beauties of the Swiss sky as seen from high altitudes, particularly the strange effects caused by the particles constituting the atmosphere.

He returned to these investigations in earnest the following summer of 1858. Similar to his previous work on glaciers, he combined his outdoor field experiments in the Alps with delicate laboratory experiments performed during the winter months at the Royal Institution. He invented the first ratio-spectrophotometer to measure the absorption of heat by gases, first by simple gases such as

Fig. 4. A view of the Wiesshorn from the Riffel. On August 17, 1861, Tyndall became the first person to stand on its summit. *Source*: Tyndall, *Hours of Exercise* (ref. 2), facing p. 91.

hydrogen and oxygen, and then throughout the 1860s by atmospheric gases more generally, including oxygen, carbon dioxide, and ozone. His results were startling, representing the first experimental verification of what is now termed the natural greenhouse effect.[34] Compound gases such as water vapor, he concluded, were the strongest absorbers of heat and thus largely responsible for warming the planet. He viewed this atmospheric heating in a positive light, suggesting that the process fortuitously made the earth habitable.

All of Tyndall's work on glaciers and atmospheric gases involved climbing, and by the mid-1860s he had become one of the preeminent mountaineers in Europe. Full of confidence in his abilities, he attacked the majestic Weisshorn in the summer of 1861 (figure 4). Several climbing parties had attempted to scale the 14,800-foot peak from many different directions, yet all attempts had ended in failure. This represented a challenge that Tyndall could not forego. "Every Swiss climber is acquainted with the Weisshorn," Tyndall gleamed. "I have long regarded it as the noblest of all the Alps, and most other travellers share this opinion. The impression it produces is in some measure due to the comparative isolation with which it juts into the heavens. It is not masked by other mountains, and all around the Alps its final pyramid is in view."[35] In an exciting narrative filled with risk and perseverance, Tyndall became the first human being to stand on its summit.

His success on the Weisshorn was a mere prelude to what had become the greatest of all mountaineering challenges of the mid-nineteenth century: the conquest of the Matterhorn. The imposing peak possessed a sublime beauty that suggested that it could (or perhaps should) never be climbed. "It drew my eyes towards it with irresistible fascination as it shimmered in the blue," Tyndall marveled, "too preoccupied with heaven to think even with contempt on the designs of a son of earth to reach its inviolate crest."[36] After spending a freezing night bivouacked on the side of a precipice midway up the mountain, his first attempt ended in failure, an experience he likened to "the removal of a pleasant drug or the breaking down of a religious faith."[37] His second attempt the next year also ended in disappointment, but not without the tantalizing achievement of gaining ground merely 600 feet from the top. According to Tyndall, he could have conquered the summit, but the sun began to sink uncomfortably low, a storm seemed to accumulate on the horizon, and his guides refused to commit. Tyndall was forced to retreat at a rocky peak below the summit, but not before engraving "John Tyndall 1864" on its side. This peak is now named Tyndall Peak.*

Tyndall was not a climber who gave up easily, and the next summer he returned to the Alps for a third attempt to conquer the mountain. Unfortunately, and unbeknownst to him, he suddenly found himself quite dead! – or, at least, that was what he was told by a passing traveler:

> [The] next morning I was accosted by a guide, who asked me whether I knew Professor Tyndall. "His is killed, sir," said the man – "killed upon the Matterhorn." I then listened to a somewhat detailed account of my own destruction, and soon gathered that, though the details were erroneous, something serious if not shocking had occurred.[38]

Something shocking had indeed transpired on the mountain. On his ninth and final attempt, Edward Whymper had finally attained the summit, the first person ever to do so. As his party of seven began their descent, however, the most famous climbing disaster in the history of mountaineering unfolded. Four climbers, including Lord Francis Douglas (1847–1865), the son of the Eighth Marquess of Queensberry, and Charles Hudson (1828–1865), perhaps the most promising young alpinist of the nineteenth century, fell over three thousand feet to their

* There are peaks throughout the globe named after the intrepid physicist-mountaineer, including Mount Tyndall in the Sierra Nevada range in California, and Mount Tyndall in the Tyndall Range in Western Tasmania.

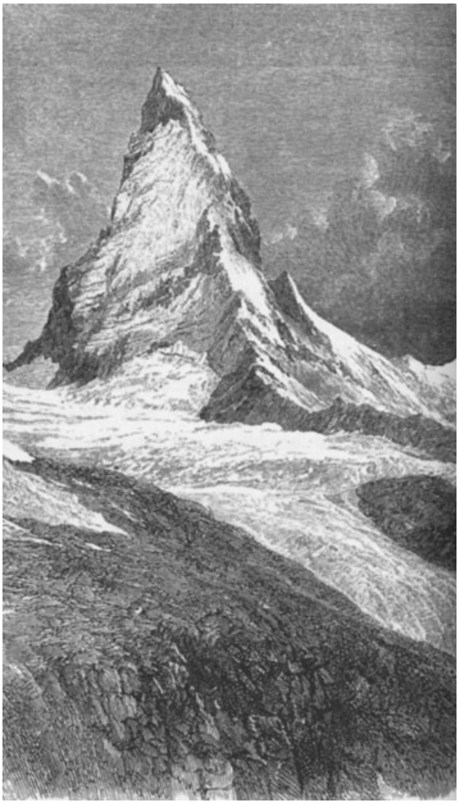

Fig. 5. The pinnacle of the Matterhorn, the premier mountaineering challenge during the golden age of mountaineering in the Alps. *Source*: Tyndall, *Hours of Exercise* (ref. 2), facing p. 117.

deaths. Tyndall spent most of the summer climbing the foothills of the Matterhorn in search of their mutilated bodies. It was a gruesome experience. Yet, as climbing attained added popularity, and higher and more remote peaks were attempted, mountaineering devolved into a dangerous – some said reckless – sport. Later that same summer, Tyndall successfully scaled the Riffelhorn, where only a week earlier, Knyvett Wilson, a Rugby schoolmaster, had perished in an avalanche. Tyndall also climbed the Schilthorn that summer, where a month earlier, Alice Arbuthnot (1842–1865), a 23-year old on her honeymoon, was struck dead by lightning.[39]

Like most climbers, Tyndall believed his experience and expert techniques would save him from a similar fate. He steadfastly returned the following year for his last attempt to scale the peak of the Matterhorn (figure 5). "In fact," he explained, "I went to Switzerland in 1866 with a particular hunger for the heights."[40] This time, his attempt to climb the Matterhorn ended in triumph.

Though not the first to stand on its summit, he had finally conquered what many had previously thought was impossible. While standing on the summit, however, he was overcome unexpectedly by a queer sadness. His impression of the mountain from below had been one of "savage strength"; yet once he looked upon it from its highest ice-filled crags, he found only "inexorable decay." The change in perspective led him to ponder his own miniscule existence. "When I look at the heavens and the earth, at my own body, and my strength and weakness of mind, even at these ponderings, I ask myself, Is there no being or thing in the universe that knows more about these matters than I do? – What is my answer?"[41] For Tyndall, the answer was a solemn one. While other climbers had fought the extreme dangers of avalanche and the erratic dynamics of ice in an attempt to find God, Tyndall found no one but himself.

His self-reflective musings aside, Tyndall was at this point completely taken with the sport of mountaineering; he was at the top of his climbing abilities. That same summer of 1866, he also attacked the Aletschhorn, the second-highest peak in the Oberland range. He took with him only one guide, something seldom done by amateurs at this stage in alpine climbing, and was astonished at the quickness and ease by which they attained the top. "I do not think I ever saw the Alps so magnificent as from this glorious pinnacle," Tyndall wrote, adding that his "object in going up was not simply to climb, but to examine the colour and polarization of the sky at this great elevation."[42] His mountaineering exploits continued to suggest to him new and exciting avenues of research, in this instance, the scattering of light by particles in the atmosphere. During his first excursion to the Alps while studying the movement of glaciers with Huxley, he noted in his journals the peculiar darkening of the sky. "As we ascended," Tyndall wrote, "the blue of the sky became deeper; and at the highest point there was something awful in the blue-blackness it assumed."[43] He reasoned that the light from the sun scattered more at lower elevations owing to water vapor in the air. He climbed the Aletschhorn in 1866, almost ten years later, with just this hypothesis in mind, carrying a pocket spectroscope during the entire ascent. "From time to time during the ascent I examined the polarization of the sky," Tyndall related, "and I wished to observe it where the hue was deepest and the polarization most complete."[44] For this, he would have to attain the summit.

After struggling with altitude sickness as he and his guide neared the summit, Tyndall finally witnessed a "deeper, darker, and purer blue" than he had ever seen, attributing the effect to the manner in which light impinged on "concentric shells of [the] atmosphere, perfectly distinct in character."[45] As usual, he took up this research with vigor in his laboratory at the Royal Institution when he returned to London. There, he sent a beam of light through a tube containing organic gases, constructing what he called an "artificial sky." The light broke up the vapor, producing a bluish tint very similar to the color he witnessed on the top of the Aletschhorn. In the paper he presented to the Royal Society in 1868 on the color and polarization of sky light,[46] he correctly attributed the effect to the process whereby light of shorter wavelengths is scattered more than light of longer wavelengths as it travels through the atmosphere. This explains why the sky is blue.[47]

When describing this work in his essay, “Scientific Use of the Imagination,” Tyndall explicitly noted the visual imagery that led to his discoveries in the laboratory:

> Not only are the waves of ether reflected by clouds, by solids, and by liquids, but when they pass from light air to dense, or from dense air to light, a portion of the wave-motion is always reflected. Now our atmosphere changes continually in density from top to bottom. It will help our conceptions if we regard it as made up of a series of thin concentric layers, or shells of air, each shell being of the same density throughout, a small and sudden change of density occurring in passing from shell to shell.[48]

British scientists and explorers had successfully bound and graphed the horizontal earth with lines of latitude and longitude and with isolines of all kinds, tidal, barometric, and magnetic.[49] By the mid-nineteenth century, naturalists like Hooker and Darwin had similarly become adroit at graphing its vertical realm as well, using zones of flora and fauna to discern troublesome patterns in the distribution of species. Like the naturalists with whom he was corresponding, Tyndall was also zoning the atmosphere vertically in his attempt to uncover the physical properties of light.

The same emphasis given to verticality in Tyndall’s work on the scattering of light by particles in the atmosphere also figured in his achievements concerning the question of spontaneous generation. He combined laboratory experiments in the Royal Institution with those performed at great heights in the Alps, specifically relying upon his ability to scale vertically up mountains to test his theories. Though Louis Pasteur (1822–1895) had completed most of his work by the time Tyndall entered the debate, questions in England persisted. Scientists had yet to prove definitively that micro-organisms were present in free air, mostly because they simply could not see them. Moreover, mixtures retained an uncanny ability to putrefy even after being heated for several hours. Through his vertical research program, Tyndall removed both of these lingering difficulties.[50]

In his previous work on radiant heat and the artificial sky, Tyndall had used floating dust to reveal the paths of light beams. In 1868, he reversed the process, using a beam of light as an instrument to reveal and then to study the floating dust. In a carefully constructed hut on the roof of the Royal Institution, he passed light through a tube, carefully expunging it of all floating matter by first filtering the air though cotton, and then passing it over a burning flame. In this manner, he produced what he termed “optically pure” air, free of all material. He then transferred his organically pure air into flasks that he sent all over the country, including to Darwin at Down House and Hooker at Kew.[51] No matter where they were opened, they became contaminated, though far more readily at the Royal Institution in central London than in the country dwellings of his eminent friends.

To verify these experiments, he also transported the flasks to his grand laboratory in the Alps, repeating similar experiments performed earlier by Pasteur on the Mer de Glace and by Félix Pouchet (1800–1872) in the Pyrenees. He separated sixty sealed flasks containing "strong infusions of beef, mutton, turnip, and cucumber" into two groups.[52] He opened the first group in a hayloft near the base of the Altesch glacier; he opened the other one on a ledge overlooking the Altesch glacier "from which ledge the mountain falls almost precipitously to the north-east for about a thousand feet."[53] Those in the hayloft were quickly contaminated, while the others in the "clean vivifying mountain air" remained pure. "They are still in the Alps," Tyndall mused many years later, "as clear, I doubt not, and as free from life as they were when sent off from London."[54] By repeating his experiments performed in and around London with air from the heights of mountains – air that was acknowledged to be far less infused with organic material – he thereby confirmed the germ theory of disease, adding yet another bulwark against the theory of spontaneous generation. As a physicist intent on demonstrating the value of his field, Tyndall had shown that careful experimentation could advance questions far beyond the field's initial reach, bringing the spontaneous-generation debate in Britain to a fitful close.

Conclusion: Tyndall's Vertical Physics

Tyndall never tired of returning to his beloved Alps. In 1877, he and his wife Louisa built a summer cottage in the Rhone valley about three hundred feet above the famous Bel Alp Hotel, a favorite gathering place for British climbers.[55] They spent every summer until 1890 trekking among the passes and glaciers near their cottage, often with a barometer and thermometer in tow. Though he continued to publish until his death, Tyndall's time in the mountains outlasted his most energetic scientific investigations. He retired from his professorial position at the Royal Institution in 1887. A party was given in his honor, with many eminent scientists and dignitaries present, and Tyndall was asked to say a few words on his own behalf. He ended his address with what had become one of his favorite metaphors:

> I have climbed some difficult mountains in my time, and after strenuous effort for a dozen hours or more, upon ice, rock, and snow, I have not unfrequently reached the top. I question whether there is a joy on earth more exhilarating than that of the mountaineer, who, having achieved his object, is able to afford himself, upon the summit a foaming bumper of champagne. But, my Lords and Gentlemen, the hardest climb, by far, that I have ever accomplished, was from the banks of the Barrow to the banks of the Thames – from the modest Irish roof under which I was born to Willis's Rooms. Here I have reached my

Fig. 6. Michael Faraday (1791-1867) and John Tyndall (1820–1893) around 1860. *Credit*: American Institute of Physics Emilio Segrè Visual Archives.

> mountain-top, and you – God bless you! – have given me a bumper which no scientific climber ever before enjoyed.[56]

The mingling of Tyndall's professional accomplishments with his mountaineering adventures should come as no surprise. He often used mountaineering metaphors, both in his own research and in his more popular writings.[57] For instance, in his widely read *Faraday as a Discoverer* (1868), he likened Faraday's work to the beauty of mountain landscapes. Faraday's "third great discovery," Tyndall explained, "is the magnetization of light, which I should liken to the Weisshorn among mountains – high, beautiful, and alone."[58] As the first person to reach the summit of the Weisshorn, Tyndall could convey authoritatively to his audience the monumental challenges that such achievements – both his climb and Faraday's work – actually entailed. Through this metaphor, the mental image of Tyndall's arduous climb up a dangerous peak made Faraday's work appear just as breathtaking. He similarly described the motivations of previous scientists, including Faraday (figure 6), as comparable to "the fascination which draws the climber to a never-trodden peak."[59] As more climbers died attempting to scale virgin peaks, the Victorian reading public became fascinated with the motives and

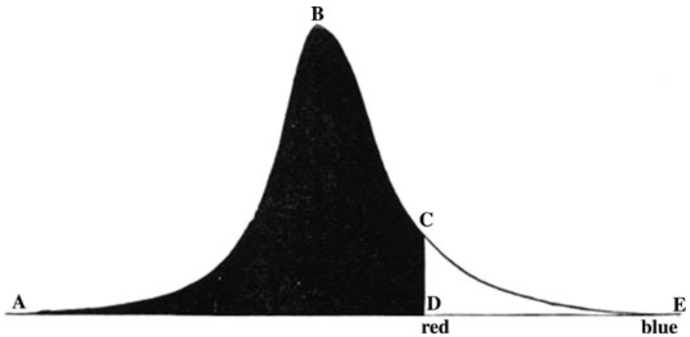

Fig. 7. Tyndall's diagram depicting visible and invisible radiation. The peak of the curve, representing invisible radiation, he likened to the pinnacle of the Matterhorn. *Source*: Tyndall, "Radiation," in *Fragments of Science.* Vol. I (ref. 60), p. 45.

processes behind it. Here and elsewhere, Tyndall was able to transfer the eerie fascination with mountaineering with a similarly incomprehensible desire to devote one's life to science–and the extraordinary demands of both.

Tyndall also explicitly used mountain metaphors in describing his work on radiant heat. In a lecture he delivered on "Radiation" in the Senate House of the University of Cambridge in 1865, he used a diagram to describe the distribution of heat, both visible and invisible, of the solar spectrum (figure 7). While the visible spectrum on the right side of the graph is relatively small, the invisible spectrum is quite large. In Tyndall's words, the curve "shoots up … in a steep and massive peak – a kind of Matterhorn of heat, which dwarfs the portion of the diagram … representing the luminous radiation."[60] He went on to explain that the actual spectral distribution seen in London always appeared a bit different from the spectrum seen in loftier settings because the solar rays have to traverse the entirety of the earth's atmosphere. "By the aqueous vapour there diffused, the summit of the peak representing the sun's invisible radiation is cut off."[61] Metaphors, if used correctly, serve to create a mental image of the unknown or unseen through what is relatively known and visible. Tyndall's mountain metaphor serves to create a mental image of what is physically unseeable through one of the most well-known and colossal mountains in Europe. Moreover, as one of the first climbers to attempt to reach the Matterhorn's summit – several exciting attempts that were widely publicized in the preceding three years in the public press – Tyndall could use his own experiences to convey his authority on the subject.

Throughout his long career, Tyndall had access to two laboratories: one in his rooms in the Royal Institution, the other, what he termed his "grand laboratory" in the Swiss Alps. In all of his researches, he combined his two laboratories to describe his research and to test his results. In the above example of radiation, for instance, Tyndall actually set up experiments in the Royal Institution and made observations of the solar spectrum while mountaineering in the Alps. Here and elsewhere, he deliberately used the verticality of the mountains as part of his research program – in this instance, heights that were far above the vapor-rich and polluted air of London. And this is the main point: Tyndall realized that answering certain questions in physics required a vertical orientation. The subject of glacier motion, for instance, demanded that Tyndall make observations vertically, through the use of poles staked at specific stations, from the bottom of a glacier to its source near the summit of mountains. These observations, which showed that a glacier moved more quickly at its terminus than at its source, then figured prominently in his controversy with James David Forbes over the viscous theory of glaciers. A focus on heights pervaded all of Tyndall's scientific investigations.

The opening quotation of my paper on the motivations for climbing dangerous peaks was autobiographical in nature. Tyndall wrote it at the height of his scientific research and mountaineering prowess. As historians of alpinism have long noted, scientists like Tyndall fashioned the sport of mountaineering. He was following the lead of others – de Saussure, Alexander von Humboldt (1769–1859), and Forbes, to name only a few – but perhaps more than any other scientist, Tyndall popularized the new sport. He gave it added value through his lectures to fashionable audiences at the Royal Institution, and vividly described it through exciting mountaineering narratives that sold quickly to a voracious public intrigued by both the practice of science and the sport of mountaineering. In the process, Tyndall became an Alpine celebrity, a giant among men during the height of the golden age of mountaineering.

What past historians have not considered is the manner in which Tyndall's attention to the vertical realm also significantly changed the scope, method, and direction of his science. Tyndall's science brought him to the mountains, but the mountains themselves further determined the approach he followed in his researches. Indeed, Tyndall's main scientific investigations came during the same period as his most energetic mountaineering feats. Between his most popular mountaineering narratives – *The Glaciers of the Alps* published in 1860 and *Hours of Exercise in the Alps* published in 1871 – he also published his most significant and popular scientific works, including *Heat Considered as a Mode of Motion* (1863),[62] *Sound* (1867),[63] *Researches on Diamagnetism and Magne-Crystallic Action* (1870),[64] and *Fragments of Science for Unscientific People* (1871). In practice and in writing, his "hunger for the heights" mingled seamlessly with his desire to advance our understanding of the natural world.

Because Tyndall (figure 8) was both an experimental physicist and a world-renowned popularizer, this intimate connection also affected how Victorians viewed the practice of physics. Tyndall was interested throughout his career in defining his field, and one quotation in particular from his *Fragments of Science* suggests how he organized it into a distinct subject:

> The term Physics, as made use of in the present Lecture, refers to that portion of natural science which lies midway between astronomy and chemistry. The

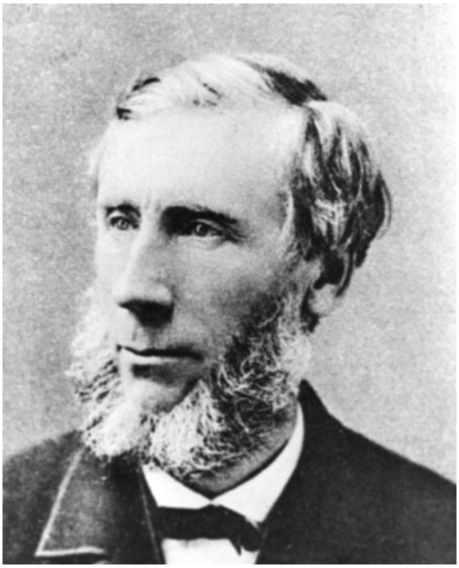

Fig. 8. John Tyndall (1820–1893) in 1873. *Credit*: American Institute of Physics Emilio Segrè Visual Archives, E. Scott Barr Collection.

> former, indeed, is Physics applied to "masses of enormous weight," while the latter is Physics applied to atoms and molecules. The subjects of Physics proper are therefore those which lie nearest to human perception: – light and heat, colour, sound, motion, the loadstone, electrical attractions and repulsions, thunder and lightning, rain, snow, dew, and so forth.[65]

The manner in which Tyndall chose to define physics matched his own interests and researches, from light and heat to thunder and lightning, those qualities "nearest to human perception." And not surprisingly, he always believed that human perceptions of Nature were "more varied and impressive in Alpine regions than elsewhere."[66] Alpine regions tend to the vertical, and Tyndall's research programs likewise followed an explicitly vertical orientation. As he practiced his science, from rock quarries to icy peaks, from the effects of the atmosphere on radiant heat to the study of the blue sky, Tyndall's interests in the fundamental forces of Nature brought him to the summits of mountains. Yet, as he climbed, he also found that he could more readily answer significant questions in the science of physics. He relied as a researcher on his ability to reach high altitudes, to study in a "grand laboratory" that crossed through several atmospheric and temperature zones. His success as an alpinist often determined the subjects of his investigations, the way he pursued them, and the manner in which he discussed them in lectures and in print. His mountaineering and science worked in unison to shape the popular perception of what physicists actually studied during a period of increasing specialization of the field."[67] That is, like natural history, geography, and other recognizable field sciences, physics was at least partly defined on the vertical, rocky faces of mountains.

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