



The
SCIENCE
behind the
MISHNAH

ספר פרפראות לחכמה
חסכת ברכות

RABBI JOEL PADOWITZ
RABBI JONATHAN SASSEN

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Dedicated to our wives

שלנו ושלכם – שלהן הוא



אשר זעליג וויס

כגן 8
פעיה"ק ירושלם ת"ו

בס"ד

תאריך: 5 באב תשס"ו

הן ראיתי את הספר פרפראות לחכמה שחיברו וערכו שני תלמידי חכמים יקרים הבקיאים במדעי החול
הרב יואל פדוביץ נ"י והרב יונתן סאסן נ"י והוטב בעיני.
בספר זה יש מבארים ומבהירים את כל עניני ותופעות הטבע שמצינו במשניות מס' ברכות. ספר זה יוצא
לאור בשפת האנגלית והוא נחוץ מאוד לצעירי הצאן בזמנינו, לתת להם הבנה יותר בהירה ועמוקה בדברי
חז"ל הקדושים.
הספר ערוך בטוב טעם ודעת, אבל אף שלא הספקתי אלא מעט, נאמנים עלי מחברי הספר ודפי הרבנים
הגאונים שהכל על טהרת הקודש ומסורת אבותינו.
באתי להרה"ג מחברי הספר שיזכו להרבות ולהגדיל תורה ולהאדירה



בא אהו

I have seen the book *Parpera'os L'Chochmah*, which was written and edited by two dear *talmidei chachomim*, who are well-versed in natural sciences: Rabbi Joel Padowitz נ"י and Rabbi Jonathan Sassen נ"י, and it is very good in my opinion.

In this book, they explain and clarify the various natural phenomena encountered in the *Mishnayos* of *Meseches Berachos*. This book is published in English and is invaluable for the youth of our time, providing them with a clearer, deeper understanding of the words of Chazal.

The book has been edited with insight and in good judgment, and even though I was only able to read a bit of it, I have confidence in these authors, and in the endorsements of the other prominent rabbis, that it is entirely consistent with our pure and holy *mesorah*.

My wishes to the rabbis who have written this book are that they should merit to spread Torah and glorify it.

Yerushalaim, 25 Iyar 5783



I would not have considered endorsing a work of this kind had I not been certain of the author's pure yir'as Shamayim and understanding of authentic Torah values. Rabbi Joel Padowitz is a long standing talmid blessed with a brilliant mind and true yir'as Shamayim. Add to that his unquenchable intellectual curiosity and he is without question the right person to write this book.

True, we studied Bava Kama without knowing what a "shor" looked like, and that did not in any way detract from our ability to delve into the depths of nezikin. Then again, so many Gemaras come alive once we understand the realities being discussed, realities that Chazal took for granted that we would all be familiar with. Certainly our young children take to Torah so much better when they can visualize and understand the cases under discussion.

And then, of course, the niflaos HaBorei, the wonders of nature that the Creator created as a vehicle for developing and enhancing our Ahavas HaShem.

The book is both exciting and inspiring and will certainly add to our appreciation of Torah and HaShem's world.

May this sefer be well received and serve as another tool to give this generation a more vivid connection to Torah.

And may its author go on to be mezakeh the tzibbur by sharing more and more of his wisdom and creativity in the service of HaShem and His Torah.

מייסד
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One of the common drawbacks of books that deal simultaneously with Torah and science is that the authors are all too often experts in one area, and less than experts in the other area. This is true of those who try to reconcile Torah and science, those who try to undermine the credibility of science from Torah sources, as well as those who raise doubts about the credibility of Torah from scientific discoveries.

This work brings together a pair of authors who, in tandem, can be considered experts in both Torah and science. Their partnership has produced a work that is informative, entertaining and most importantly very inspiring. Without trying to reconcile every aspect of Torah with modern scientific discoveries, they have enabled us to have a better understanding of halachic concepts that depend on the amazing world the Almighty has created for us.

Rav Yitzchak Hutner zt'l taught that the Almighty reveals Himself to man in three different ways. The first is through the Torah. The second is through His creation, the world of nature. And finally, through history. This work will help anyone who delves into it to get a better understanding of the Almighty through both Torah and science. (We need to leave His revelation through history for others to expound upon.)

I have been privileged to know Jonathan Sassen for decades, from his time as a beginning student in our Yeshiva, already an expert in his branch of science. He has grown into a knowledgeable talmid chacham, while continuing to grow in his professional field. This combined with sterling middos and humility gives him utmost credibility in his contribution to this volume. I only know Rabbi Padowitz by reputation, but combined with his experience and accomplishments I am confident in recommending this work without hesitation. It is a work that will enhance our Torah knowledge, our scientific understanding, and most importantly a greater love and appreciation of the Almighty.

Rabbi Shaya Karlinsky

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נחל רפאים 34 רמת בית שמש א'

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ראש הישיבה
ישיבת תורת שרגא
בית וגן ירושלים

Rabbis Joel Padowitz and Jonathan Sassen have embarked on a grand project and journey designed to enlighten and educate our youth and the public at large regarding the scientific backdrop of משניות ברכות. Their focus is of a dual nature: a) A general edification of basic scientific principles that span a rich variety of variegated topics that illuminate many of the משניות. b) A profound acknowledgement of the amazing handiwork of Hashem in the creation process that beckons to us to recognize His majesty and grandeur and articulate our praise and thanksgiving in a fulsome manner without any reservation.

In our נוסח התפילה we recite "מה רבו מעשיך ה'". Often it is translated as "How great is your handiwork...". However, embedded in this language is also the idea "How multifarious and multihued is your craftsmanship." Many early philosophers and scientists attempted to reduce all of creation to one underlying principle, but the Torah *Weltanschauung* rejects the notion categorically. מה רבו implies how diverse and multifaceted is your workmanship.

Hagaon Harav Aharon Halevi Soloveitchik זצ"ל often cited in the name of his mother א"ה that there are two different perspectives in every oeuvre. One is that of a poet who is borne aloft by a creative spirit that he harnesses to engender and create a tapestry of spirit that will resonate in the hearts and minds of its readers. The other is that of a scientist whose mastery of detail and minutiae is designed to underscore the complexity and intricacy of every creation of Hashem Yisboroch. It's astounding to recognize and witness the meticulous, dazzling and gargantuan forces and elements that comprise the creation and the even more amazing harmonious interplay of all these components in the most wondrous of fashions.

The ספר פּרָפְרָאוֹת לְהַקְמָה written by two outstanding scientists, בני תורה, and יראי שמים is a composite of both aforementioned stimuli. Their exhaustive analysis of nature and its phenomena is breathtaking in its beauty and splendor. My immersion from their electron microscope engendered in me the שמחה of a poet who sees the גדלות הבורא in all of its splendor. The diagrams, illustrations, pictures, drawings, and even the minute examination of syntax and linguistics of the ספר just highlighted and concretized for me the consummate artistry of the בריאה. בריואה חז"ל. The Divine Architect has wrought a wonderful craftsmanship that summons us to see the יד ה' in his marvelous בריואה.

We are overly מכיר טוב and grateful to these two maestros who have striven indefatigably to enlighten and illuminate משניות in מסכת ברכות in this grandiose enterprise and provide us with a window to the בורא עולם that can only generate a cascading, overflowing שבה והודאה to Hashem Yisborach for His bountiful חסד to His created beings.

הכותב והחותרם לכבוד התורה ולומדיה

Avishai C. David

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Jonathan would like to thank his wife, Debbie, for many decades of love, support, encouragement, initiative, and leading by example in following your dreams, pushing through barriers, and staying focused on using our resources for *kavod Shamayim*.

Joel expresses his sincerest appreciation to his wife and life partner, Shelly, for her ongoing kindness, love and support. Your selfless dedication to our family, which helps each of us to reach our full potential in countless ways—including the creation of this sefer—is an ongoing inspiration. He also expresses his deepest gratitude to his grandfather, Bernhard Lazarus, ז"ל; mother, Marilyn Lazarus; and business partner, Moishe Hartstein—even if your direct involvement in this book was not material, I cannot imagine how it would have been possible without each of your involvement in my life over the decades. Thank you!

We are also very grateful to the staff of Mosaica Press whose editorial input, creativity, and overall professionalism transformed a simple manuscript into this beautiful work. *B'ezras Hashem*, we will continue our fruitful partnership with future volumes of *The Science behind the Mishnah*.

We take this opportunity to acknowledge the following people (in alphabetical order), who so generously allowed us to use their images without remuneration:

Ryan Ace, Eberhard Frost, Professor Doug Goff, Mike Korostelev, John Lok and Space Needle LLC, Dr. Ralph T. Muehleisen, National Science Foundation, Professor Hema Priyamvada Ravindran, Dr. Beverly Rubik, Chayim Tzvi Schneider, and Professor Ari Zivotosky. We are also grateful to Lina Erez for the wonderful artistic work she provided for many of the images in this *sefer*.

Finally, we express our deepest *hakaras ha'tov* to Hashem for the truly innumerable blessings that He has showered upon us, which have enabled us to be the agents who brought this project to fruition. It is our sincerest hope and prayer that we have fulfilled His will and that this *sefer* will bring His people a little closer to Him.

Joel and Jonathan
Ramat Beit Shemesh, Israel
תשפ"ד / 2024

READ THIS FIRST

IN EVERY GENERATION, our rabbis have taught us that Torah study is of paramount value, both as a means to an end (i.e., to enable the proper performance of all the other mitzvos) and as an end in itself. Many of those rabbis have emphasized the value and benefits of understanding the workings of the natural world—what we today would call science.¹ The Hebrew title of this *sefer*, ספר פרפראות לחכמה, is a reference to the Mishnah in *Avos* 3:18. There, Chazal liken the relationship between science and Torah to that of tasty foods that accompany the main meal in order to whet one's appetite and to make the main meal more enjoyable.

It is well known that the *chachmei haTorah* throughout the generations have expressed concerns about the value—and potentially even the danger—of secular studies. It would seem, however, that almost without exception, these misgivings did not extend to the study of the natural sciences. To the contrary! The Gemara,² *Rambam*,³ *Chovos Halevavos*,⁴ *Kuzari*,⁵ Rabbi Yosef Karo,⁶ the Maharal of Prague,⁷ and the Vilna Gaon⁸ (to name but a few) all wrote of the benefits, importance, and sometimes even the religious obligation to study science. Collectively, they identify two distinct reasons why we should seek to understand the natural world. (These reasons are aside from various pragmatic and extrinsic considerations, such

1 To be clear: By science, we mean the natural sciences, such as physics, chemistry, and biology, and not fields of study often referred to as social sciences, such as history, economics, and politics (and certainly not the humanities).

2 *Shabbos* 75a: “שמצוה על האדם לחשב תקופות ומזלות...”

3 *Rambam*, *Hilchos Yesodei HaTorah* 4:12.

4 *Shaar Habechinah* 2.

5 *Kuzari* 2:64.

6 *Kesef Mishnah*, *Hilchos Yesodei HaTorah* 4:13.

7 *Nesivos Olam*, *Nesiv HaTorah* 14.

8 As quoted by Reb Baruch Schick of Shklov in his translation of Euclid's book on geometry, the Gaon said: “Proportional to what one lacks in his understanding of the sciences (משארי החכמות), he will lack a hundred times in his understanding of Torah, because the Torah and science are interconnected.”

as enabling one to earn a livelihood or raising the esteem of *talmidei chachamim* in the eyes of others.)

The first and most basic reason is that scientific knowledge is often essential for a correct understanding and fulfillment of the Torah itself. The Torah is our guide for how to interact with the world in accordance with the *ratzon Hashem*. Since the physical world comprises nature and is subject to its laws, scientific knowledge is often required to ensure halachah is properly understood and upheld. An endless number of questions in *hilchos Shabbos*, *kashrus*, and *niddah*, for example, cannot be resolved without an understanding of physics, chemistry, or biology. Perhaps the most famous example of Chazal expressing this value is the Amora Rav, who spent eighteen months with herdsmen to study which blemishes on livestock were permanent and which were temporary in order to correctly implement *hilchos bechoros*.⁹ Similarly, the Amora Shmuel declared that he had mastered astronomy to the point that he knew the paths of the heavenly bodies as well as he knew the paths of his hometown Neharde'a,¹⁰ enabling him to rule precisely on halachic matters such as *Kiddush Hachodesh*.

The second reason why every Jew should have a basic understanding of, and familiarity with, the workings of the natural world is because it enhances one's love and reverence for Hashem. Love and reverence are meant to constitute the core of our relationship with Hashem and dictate the way we are to relate to Him at all times. Such a relationship requires our knowing Him to the best of our abilities. Since it is only possible to know Hashem through what He does (as opposed to what He is, which is unknowable),¹¹ we must study His works. Of these works, two are accessible to us: the Torah He revealed to us, and the world He created for us. Since the Torah is a more direct and profound reflection of His will, its study must take priority. The study of nature, however, cannot and should not be ignored as a supplementary and invaluable means to the ultimate goal of loving and revering Hashem. *Rambam* famously wrote:

9 *Sanhedrin* 5b.

10 *Berachos* 58b.

11 See *Chovos Halevavos*, *Shaar HaYichud* 10; *Shaar HaBechinah*, *Pesichah*.

And what is the path to love and revere [Hashem]? When a person thinks about His works and His great and wonderful creations and sees in them His inestimable, infinite genius, one will immediately love and praise and exalt [Hashem] and be filled with a great desire to know His Great Name. As David [Hamelech] said: “My soul thirsts for G-d, for the living G-d.”¹² And when one thinks of all these matters, he will immediately be taken aback and stricken with awe, realizing that he is a puny creature, lowly and dim, standing with an insignificant and minimal knowledge in the presence of the All-Knowing, as David [Hamelech] said: “When I see Your heavens, the works of Your fingers—what is a human that You should take note of him?”¹³

Similarly, the *Rema* stated: “...They did not forbid the study of the words of the scientists nor of their scientific research; to the contrary, through these, we can know the greatness of Hashem.”¹⁴ More recently, several notable rabbis of the twentieth century were well known for emphasizing the importance of considering the wonders of creation to help instill *emunah*, love, and reverence of Hashem, including the Chazon Ish,¹⁵ Rabbi Shlomo Wolbe,¹⁶ and Rabbi Avigdor Miller.

In this work, we have done our very best to provide the Torah-true community with a resource that facilitates both of these roles that scientific understanding can play within a larger framework of proper *avodas Hashem*. Specifically, we have attempted to explain the scientific topics encountered in the Mishnah to give the reader a better, deeper understanding of the Mishnah itself. At the same time, we have taken the liberty of explaining certain related, more general issues to give the reader a better understanding of the larger scientific principles at work. We expect this broader perspective will provide insight into other areas of Torah-true living as well.

12 *Tehillim* 42:2.

13 *Ibid.* 8:4. *Rambam, Hilchos Yesodei HaTorah* 2:2.

14 *Rema*, responsum 7.

15 See *Emunah U'Bitachon* 1.

16 See *Alei Shor* 2:2:16, *Emunah, Vaad Rishon*.

Along the way, we have also taken the opportunity to explain a few of the innumerable details in creation that demonstrate Hashem’s infinite genius and unending love for us. We do not view this *sefer* as yet another of the many beautiful books that have recently cropped up in the genre of “*sifrei niflaos haBorei*.” The wonders that Hashem created and continues to create are, in truth, so much more profound than the typical fare of amazing plants and animals found in such books. Without science, every feature of our gorgeous universe, from snowflakes to sunsets, seems like yet another marvel in an endless kaleidoscope of unrelated mysteries. Yet, the more one understands the universality of nature’s laws and of its building blocks, the more one sees the unity, elegance, and interconnectedness that underpins all of creation—what we know to be a manifestation of *yichud Hashem*. It is our hope and prayer that our explanations of some of the basic concepts of physics, chemistry, biology, and Earth science will start the reader on the road to actually *understanding* some of Hashem’s genius and *feeling* His loving, active presence in our lives as revealed by the details of the natural world. This, in turn, will enable readers to love and revere Hashem more deeply, just as the *Rambam* and *Rema* prescribed.

It would be disingenuous—and perhaps even irresponsible—were we not to mention the two basic reservations our rabbis have in fact expressed regarding the study of science. The first, and more severe, is the possibility of heretical (anti-Torah) ideas being intertwined within scientific writings. In our times, this is a very real concern. One must be exceedingly careful regarding where one gets his scientific information, which sometimes is presented by authors whose agendas run contrary to Torah values. The second concern is for *bittul Torah*, wasting one’s precious time on scientific studies, when one would better serve Hashem by studying Torah itself. This issue is also very serious and certainly should not be taken lightly—especially since life tends to be shorter than most of us estimate, and the Torah is larger than most of us imagine.

Regarding the concern for heresy, we hope and pray that we have had the *siyata d’Shmaya* to protect us from including anything in these pages that is inconsistent with Torah or its values (*chas v’shalom*). We have shown this *sefer* to our *rebbe’im*

and to other competent *talmidei chachamim* who have reviewed the text in its entirety and have confirmed that this is indeed the case. The issue of *bittul Torah* is more complex and nuanced. Learning this *sefer* certainly constitutes the mitzvah of *talmud Torah*, and one should not read any of it before reciting *Birkas HaTorah*—let alone bring it into the washroom! However, questions of *bittul Torah* must be considered in the context of what one would be learning instead. The reader is encouraged to ask his Rav for guidance if the reading of this *sefer* is coming at the expense of other Torah learning.

The most challenging aspect of writing this *sefer* has revolved around the question of who would be reading it. We expect there will be school-aged boys and girls filled with a healthy curiosity to understand the world around them. We hope to indulge that delightful attitude and have tried to entertain, and at times even to enthrall, such readers. At the same time, we hope that many adults with more substantial vocabularies, educations, and life-experience will peruse these pages in search of answers to questions about a particular Mishnah or a specific scientific phenomenon, or perhaps even read it from cover-to-cover for their general edification. We have tried to put something here for everyone. To that end, we hope that certain readers will persevere through some of the more difficult language and concepts, while others will view some of the more frivolous images and introductory content with a charitable eye.

We conclude this introduction with a personal reflection. This *sefer* is the product of two fathers with strong scientific backgrounds. We love Hashem and we love learning His Torah. We also love to share our insights into the *niflaos haBorei* with our children—especially when they have had questions that were not answered in their yeshivos or Bais Yaakovs. A great deal of our enthusiasm for sharing these insights, which is what ultimately motivated us to write this *sefer*, was engendered within us by our *rebbe*, Harav Hagaon Chaim Zev Malinowitz, *zt”l*.

Rav Malinowitz was a *lamdan* and *dayan* par excellence, who quite literally knew *kol haTorah kulah*, and used his abilities to serve Klal Yisrael in numerous ways, including as the editor of the ArtScroll Schottenstein Talmud. As a young man, he was fascinated by the famed American Jewish physicist Richard Feynman. The

Rav was impressed by how Feynman creatively solved problems and explained complex ideas in simple ways. Rav Malinowitz aspired to do something similar in the realm of Torah and *lomdus*. Rav Malinowitz was especially fond of the following Feynman quotation, which he cited in shiurim on *Chovos Halevavos* and in at least one Shabbos *derashah*:

I have a friend who is an artist and has sometimes taken a view that I don't agree with very well. He'll hold up a flower and say, "look how beautiful it is," and I'll agree. Then he says, "I as an artist can see how beautiful this is, but you as a scientist take this all apart, and it becomes a dull thing," and I think that he's kind of nutty. First of all, the beauty that he sees is available to other people and to me too, I believe. Although I may not be quite as refined aesthetically as he is...I can appreciate the beauty of a flower. At the same time, I see much more about the flower than he sees. I could imagine the cells in there, the complicated actions inside, which also have a beauty. I mean it's not just beauty at this dimension, at one centimeter; there's also beauty at smaller dimensions, the inner structure, also the processes...The science knowledge only adds to the excitement, the mystery, and the awe of a flower. It only adds. I don't understand how it subtracts.

Rav Malinowitz emphasized the importance of seeing the *gadlus haBorei* in every detail of both Hashem's Torah and His creation, and then channeling that inspiration into a deep and abiding *hakaras ha'tov* toward Hashem. He internalized this value from the *sefer* that he considered the chief influence in his life, *Chovos Halevavos*, and he deeply imbued it into us. We pray that this chain of inspiration will continue to you, and that this *sefer* will in some small way strengthen the *emunah*, *ahavah*, *yirah*, and *hakaras ha'tov* that binds Klal Yisrael with our Creator, thereby bringing *zechus* to Rav Malinowitz, *zt"l*, and hastening the coming of the *geulah*, *bi'meheirah b'yameinu*.

HOW TO USE THIS BOOK

This *sefer* was structured as a running commentary on topics encountered in *Maseches Berachos*, so it follows the order of the Mishnayos. There is no need, however, to read it in that order. We anticipate that many will prefer to flip through it, much like one would read a magazine, looking into whichever topics pique one's interest. We encourage you to do so, as there is so much to learn here, and Chazal have taught us that “אין אדם לומד תורה אלא ממקום שלבו חפץ”—A person only learns Torah from a place where his heart is interested.”¹⁷

Because there is no particular beginning or end from the perspective of scientific content, many chapters refer to material that is supplemented by content in other chapters. We made explicit mention of such instances when we felt that they were especially important. We have, however, done much more than that. We have prepared a comprehensive glossary, which can be found at the back of this *sefer*, which explains hundreds of technical and scientific terms used throughout the text. Readers are encouraged to make use of the glossary, which contains a world of additional information. It also serves as a more comprehensive cross-referencing tool. Words that can be found in the glossary appear in boldface and in color throughout the text. In chapters that use a given term more than once, it is only in boldface and in color the first time that it appears within that chapter.

Although we encourage you to enjoy this book in any order you choose, we can imagine there will be certain people, such as educators, who would like to use the text as a more formal, scientific resource. The following lists provide possible ways to organize the chapters in terms of scientific topics, and we have provided a suggested sequence for anyone who is looking to use them as part of a more formal curriculum. Many chapters cover more than one subject, so they may appear in lists below more than once.

17 *Avodah Zarah* 19a.

PHYSICS

Atomic structure and electricity	Chapter 30: Lightning and Electricity
Electromagnetic spectrum and black body radiation	Chapter 26: The Color of Fire
Infrared	Chapter 10: Snakes
Light scattering	Chapter 1: Twilight
Light absorption, reflection, and color	Chapter 3: Color Vision
Convex reflection	Chapter 8: Convex Reflection
Sound waves, amplitude, frequency, and the speed of sound	Chapter 31: Thunder and Sound
Sound and vibration	Chapter 4: Whispering
Air pressure	Chapter 11: Wind and Air Pressure

CHEMISTRY

Atoms, molecules, and combustion	Chapter 24: Hydration and Cellular Respiration
Oxidation and chemical bonds	Chapter 25: Sparks and Making Fire
Covalent bonding, ions, and acids	Chapter 17: Vinegar and Acids
Organic molecules and macro-molecules	Chapter 15: Bread and Nutrition
Solubility, ionic bonding, osmosis, and crystal structure	Chapter 22: Salt, Food Preservation, and Crystals
Water phase changes	Chapter 12: Rain, Precipitation, and the Water Cycle
Fermentation	Chapter 14: Wine and Fermentation
Milk	Chapter 19: Milk
Cheese	Chapter 20: Cheese

GENERAL BIOLOGY

Bacteria, cells, and membranes	Chapter 22: Salt, Food Preservation, and Crystals
Hydration, cells, and cellular respiration	Chapter 24: Hydration and Cellular Respiration
Fungi	Chapter 16: Mushrooms and Truffles
Plants	Chapter 5: Flax
Trees, vegetables, and fruits	Chapter 13: Fruits and Vegetables
Insects	Chapter 18: Grasshoppers and Locusts
Snakes	Chapter 10: Snakes
Mammals and milk	Chapter 19: Milk
Fat and energy storage	Chapter 2: Fats

HUMAN BIOLOGY

Digestion and the gastrointestinal tract	Chapter 27: Digestion
Nutrition	Chapter 15: Bread and Nutrition
Fat	Chapter 2: Fats
Hydration, cells, and cellular respiration	Chapter 24: Hydration and Cellular Respiration
Bacteria, cells, and membranes	Chapter 22: Salt, Food Preservation, and Crystals
Speech and the vocal apparatus	Chapter 4: Whispering
Sense of sight and the eyes	Chapter 3: Color Vision
Sense of smell and the nose	Chapter 21: Incense and Our Sense of Smell
Sense of taste and the tongue	Chapter 23: Water and Our Sense of Taste
Sense of hearing and the ear	Chapter 31: Thunder and Sound

EARTH SCIENCES

Introduction to astronomy	Chapter 28: Meteors and Comets
The Earth's rotation	Chapter 6: Sun Movement
Seasons	Chapter 7: Halachic Hours
Plate tectonics	Chapter 29: Earthquakes and Plate Tectonics
Forces of erosion and activity on the surface of the Earth	Chapter 32: Mountains, Hills, Seas, and Rivers
The Atmosphere and wind	Chapter 11: Wind and Air Pressure
Precipitation and the water cycle	Chapter 12: Rain, Precipitation, and the Water Cycle
Atmospheric effects on light	Chapter 1: Twilight
Lightning	Chapter 30: Lightning and Electricity
Thunder	Chapter 31: Thunder and Sound

CHAPTER ONE

TWILIGHT

מַאימְתִי קורין אֶת שְׁמַע בְּעֶרְבִית? מִשְׁעָה שֶׁהַכֹּהֲנִים נִכְנְסִים
לֶאֱכֹל בְּתְרוּמָתָן, עַד סוֹף הָאֲשֶׁמוּרָה הָרִאשׁוֹנָה; דְּבַרֵי רַבִּי אֱלִיעֶזֶר.
וְחֻכְמִים אוֹמְרִים: עַד חֲצוֹת. רַבֵּן גַּמְלִיאֵל אוֹמֵר: עַד שֶׁיַּעֲלֶה עֲמוּד
הַשָּׁחַר.

From when may one recite the *Shema* in the evening? From the time that the Kohanim enter to eat their *terumah* until the end of the first watch—[these are] the words of Rabbi Eliezer. But the Sages say: Until midnight. Rabban Gamliel says: Until the break of dawn.

Berachos 1:1



▲
FIGURE 1.1. Yerushalayim at dawn, a short time before sunrise.
Where do those beautiful colors in the sky come from?

WHY DOES THE SKY LIGHT UP BEFORE THE SUN HAS RISEN?

Twilight is that special time of day when the sky is not dark, yet the **Sun** is not visible above the **horizon**. It actually happens twice every day: at dawn, before the Sun has risen, and at dusk, immediately after the Sun has set. In halachah, it is not



▲
FIGURE 1.2. This is NASA's Juno planetary probe launching atop an Atlas V rocket. About one minute after takeoff, a rocket like this will have traveled through the 100 kilometers (about 62 miles) of Earth's atmosphere and be in empty space.

sunrise, but rather the break of dawn (עמוד השחר) that marks the beginning of a new day.¹ This happens more than an hour before sunrise when the first rays of sunlight become visible in the eastern sky.²

We have all enjoyed the wonder of the dawn. It is one of the most beautiful and peaceful times of the day. The gradual transition from darkness to light is actually a *chessed* from Hashem to allow our eyes to adjust to the changing brightness so they won't be damaged.³ The first blessing of the *Shema*, which we recite in the early morning and early evening, alludes to this with the words "הַמְאִיר לְאָרֶץ וְלְדָרִים עָלֶיהָ"⁴—He Who illuminates the Earth and those upon it with compassion."⁴ But have you ever wondered where the light of dawn comes from if the Sun isn't visible over the horizon?

1 *Megillah* 20a–b.

2 *Mishnah Berurah* 89:2.

3 *Kitzur Shulchan Aruch* 32:27.

4 *Ibid.*

It's not at all as simple as you may have thought. For example, there is no such thing as dawn on the **Moon** or on a **planet** like Mercury. So why does it happen here on Earth?

Hashem custom-made our planet Earth with love in every way. One of those ways was to wrap it in a blanket of air. It may sound strange to compare the air around us to something as thin as a blanket, but it shouldn't. The layer of air around us is actually much thinner than most people think. It hardly takes a minute before a rocket launched from Earth leaves this layer and is no longer surrounded by any air at all—just empty space (see Figure 1.2). And as we shall see, empty space is very different from air!

The layer of air around us isn't just thin like a blanket. It also works like a blanket, ensuring that we never get too hot or too cold. This layer has a special name: the Earth's **atmosphere** (see Figure 1.3).

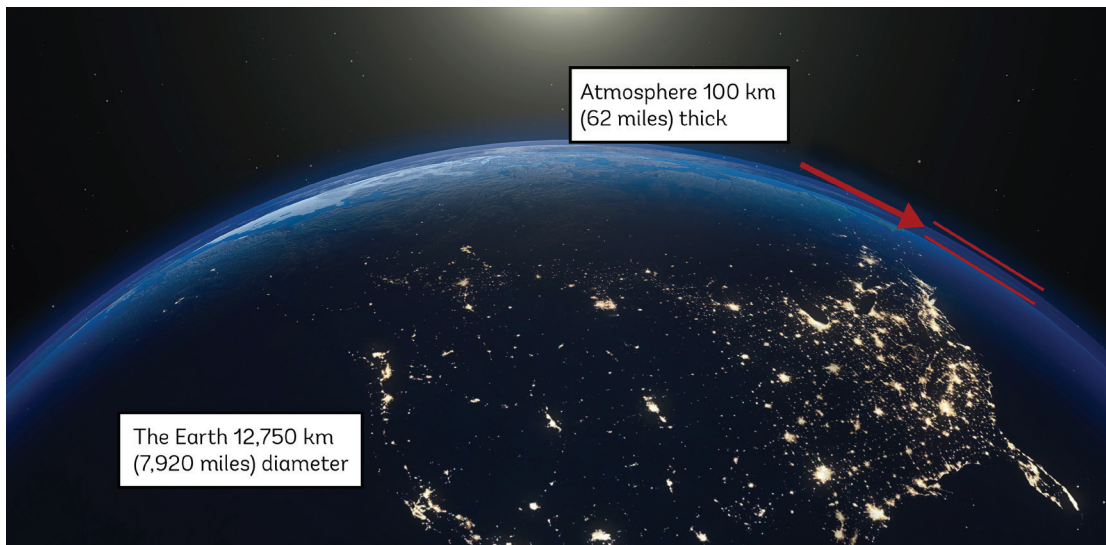
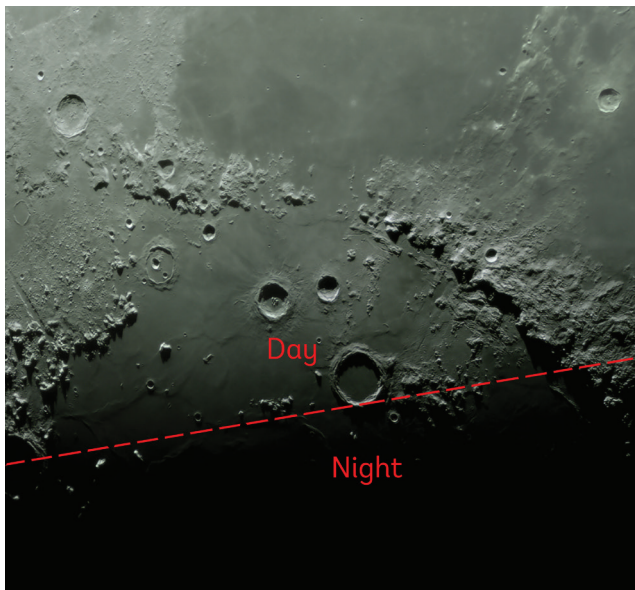


FIGURE 1.3. This is an actual photograph of the Earth at night. All those light blotches in the darkness are city lights throughout North America. On the far right you can see an outline of much of the State of Florida. The strip of lights on the left are cities along the Pacific coast, with Vancouver, British Columbia (Canada) as the most northerly large blotch, and San Diego, California (and even some lights from Tijuana, Mexico) at the bottom of it. Most of the surface of the Earth (especially the Pacific Ocean on the left and Atlantic Ocean on the far right) is entirely dark at night. The blue arc of light surrounding the planet is our atmosphere. Above it, the atmosphere ends and the blackness of space begins. In this picture, you can get an idea of how thin the Earth's atmosphere is relative to the size of the entire planet.

OUR ATMOSPHERE

Our atmosphere does a lot of things. Perhaps the most obvious one is that it provides us with the air we breathe. But it does other things as well. Imagine you were on the Moon. You would need a spacesuit to provide you with air to breathe, since there is no atmosphere on the Moon. Picture yourself looking out of your Moon home's window: It is nighttime and completely dark outside, except for the faint starlight. Without warning, a moment later, the edge of the Sun appears over the nearby mountains. Sunrise! Everything lights up as bright as day—because it is day! On the Moon, there is no such thing as dawn. *נִמְוֵד הַשָּׁחַר*. One moment it is black night, and hardly a moment later the surface of the Moon is fully lit up.

So why is there a dawn every day on Earth, but never on the Moon? Because of our atmosphere!



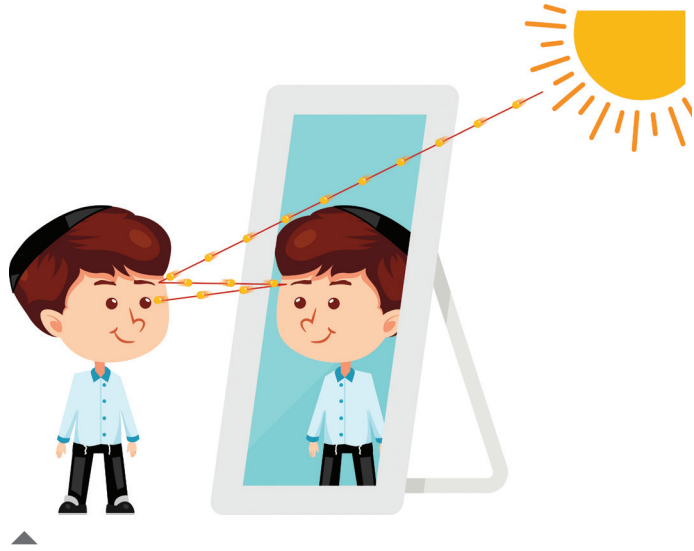
▲
FIGURE 1.4. This is an actual photograph of the Moon. The dotted line divides between where sunrise has occurred and where it hasn't yet.

Our atmosphere is filled with air, which makes it very different from empty space. When we look at air, we don't see anything, but that doesn't mean that nothing is there. Air (like almost everything) is made of countless very tiny particles (pieces) called **molecules**. Even if you can't see air molecules, you can feel them simply by moving your hand quickly and feeling a gentle wind of air molecules press against your hand. You wouldn't feel that on the Moon.

LIGHT

One way to imagine light is as countless extremely tiny balls (scientists call these balls **photons**). When these little balls bump into something, they can either be

absorbed or bounce off. For example, look in a mirror and you will see a reflection of your face. What you are seeing is light that bounced off your face onto the mirror and then bounced off the mirror and into your eyes (see Figure 1.5). Light bouncing off something is called **reflection**. When all the light coming from any one particular direction reflects off a smooth surface at the same angle, such as off a mirror, then all the photons “stay together” in their original formation, and we see a copy of the original object. Mirrors, however, are special cases of reflection. Usually, photons bounce off objects in every direction, so our eyes just see the color of the photons that bounced off, without seeing a recognizable image of the original light source.



▲ FIGURE 1.5. You can see your forehead in the mirror, even though it isn't actually there. This is because of photons that reflected off your forehead, toward the mirror, and then reflected back off the mirror's surface into your eyes.

The reflection of light off a mirror is something like a ball bouncing off a smooth wall. When you throw a ball against a smooth surface, it bounces back in a very predictable direction. If you have good aim, you could probably throw a ball against a wall ten times and catch it again each time without ever moving your feet. Now imagine that instead of a wall, you were throwing a small bouncy ball against a basketball. Do you think you could guess which direction it would bounce off the basketball? If you think you could, why not try it? Throw a small ball a few times against a basketball and see just how unpredictably it rebounds. If you threw a thousand small bouncy balls against a pile of basketballs, can you picture how the balls would bounce back, scattering in every direction?

A simplified way of thinking about what happens when the Sun's light passes through our atmosphere is to imagine the light from the Sun as being made of

countless photons, each like a tiny bouncy ball, and the atmosphere as countless air molecules, each like a basketball. In our atmosphere, there is a lot of empty space between each molecule, so most of the photons coming from the Sun pass straight through the atmosphere without bumping into any air molecules (see Figure 1.6). However, some of the photons from the Sun do bump into the atmosphere's air molecules. When this happens, the photon is knocked into a totally different, unpredictable direction. Since there are actually many, many photons bouncing off the molecules in the atmosphere, the overall effect is to spread some of the Sun's light over the entire sky. This is called **scattering** of the light.

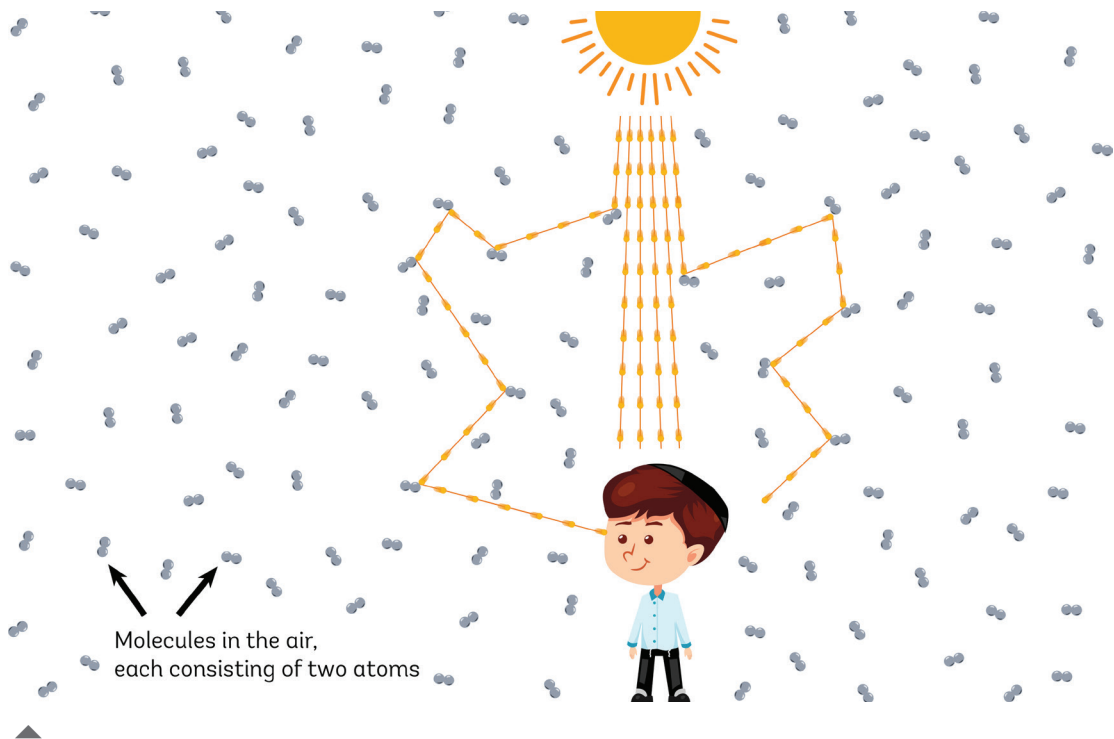


FIGURE 1.6. This is an illustration of how you might imagine most photons from the Sun passing directly through the atmosphere, while some collide with air molecules and are scattered in unpredictable directions.

The light that we see in the sky before sunrise is scattered sunlight that spreads around the atmosphere. It is probably easier to make sense of this with an illustration. Look at Figure 1.7. The person standing at Position A on the Earth's surface will not be able to see the Sun directly. In other words, sunrise has not yet

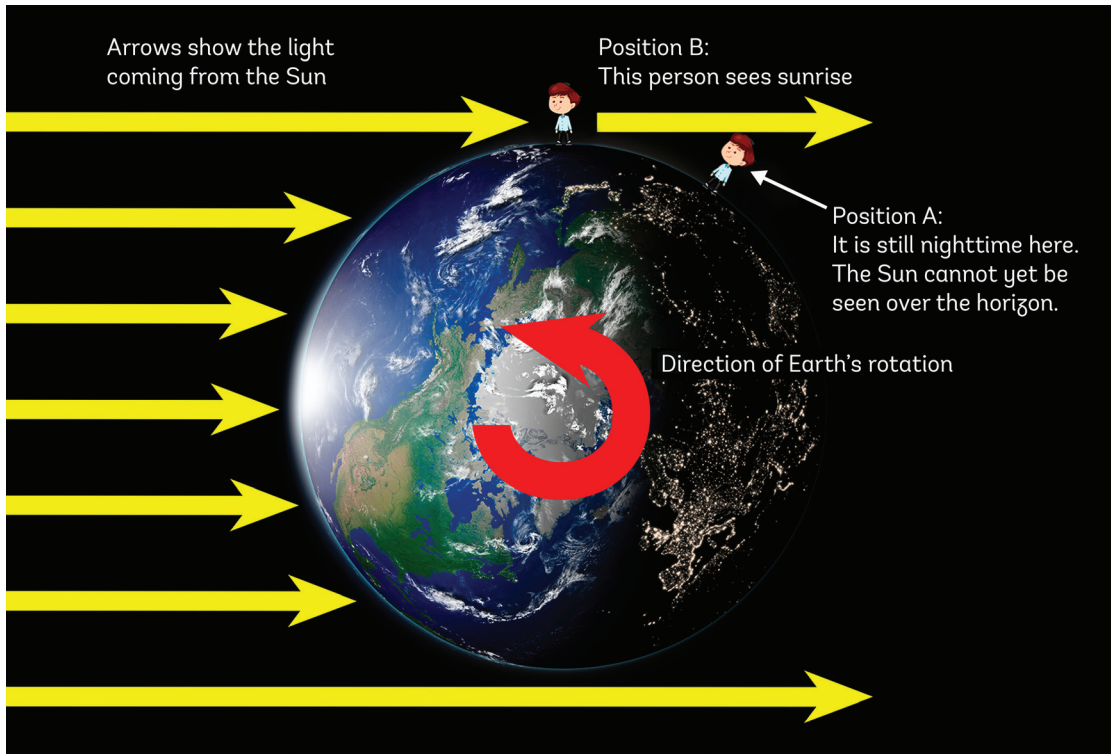


FIGURE 1.7. A view of the Earth from above the North **Pole**. From the direction of the Earth's rotation (as signified by the red arrow), you can see that it is currently nearing the end of the night for the person standing at Position A. In an hour or so he will have moved to Position B. (The Earth rotates 360° in 24 hours, so each hour it rotates 15° .) The person currently standing at Position B would have just been able to see the Sun rise over the horizon.

occurred where he is standing. If he looks at the sky in the direction of the Sun, soon he will be able to detect the break of dawn (עמוד השחר) as the sky begins to fill with scattered sunlight. It is almost like the light is “sneaking around the corner.” As the Earth rotates and he moves toward Position B, the sky will brighten with more and more scattered light. When he finally reaches Position B, the Sun will be in a direct line of sight, and sunrise will occur as the ball of the Sun appears on the horizon.⁵

5 Technical point: There is another atmospheric effect called “refraction,” which slightly bends light from the Sun toward the Earth. Refraction bends light uniformly in a single direction; it is something entirely different from the scattering we have been discussing, in which light spreads out in all directions. When we view light refracted through our atmosphere, it retains a coherent image (i.e., the Sun can still be seen

We have answered our initial question regarding why the sky lights up before the Sun has risen. Before we conclude this topic, we should consider one more question that almost every person has wondered about some time in their life, since we are most of the way to the answer already: Why is the sky blue?

WHY IS THE SKY BLUE?

Up until now, we have been discussing the scattering of the Sun's light in the atmosphere, but not all of the Sun's light scatters in the same way. This is because not all photons are the same. Depending on how much **energy** they have, we perceive photons as having a different colors. Thus, we might say that blue light is made of blue photons, and red light is made up of red photons. The light that comes from the Sun is actually a mixture of many different colors that all combine to make it the yellow-white color that we usually see. The chances that an individual photon will be scattered in the atmosphere depends very strongly on its color. Blue photons scatter much more readily than photons of the other colors.

During most of the day, when the Sun is high in the sky, its red light doesn't travel through enough atmosphere to be scattered significantly. At the same time, a lot of blue light is scattered and spreads around the atmosphere (see Figure 1.8). This is the source of our midday blue sky (Figure 1.9). The strong scattering of blue photons also means that they travel very far around the atmosphere, so blues are the first colors we see at dawn (עמוד השחר) and the last colors we see at dusk (צאת הכוכבים) (Figure 1.10).

as a sharply defined ball, despite the refraction). This is in contrast to scattered light, as we have described above. Refraction's net effect is to make sunrise visible about two minutes earlier than it would have been if the Earth had no atmosphere. The precise amount of refraction that occurs depends on latitude, elevation, **temperature**, and **humidity** at the time of sunrise.

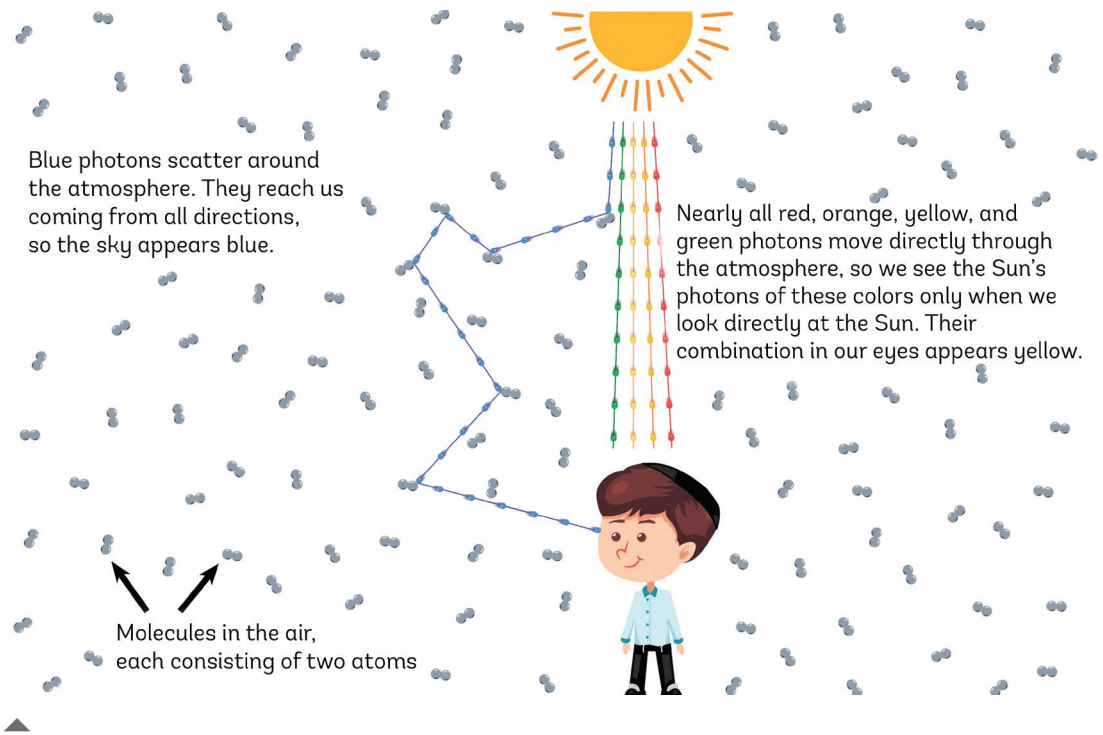


FIGURE 1.8. Blue photons are much more likely to be scattered, so we see them coming from all directions.



FIGURE 1.9. During most of the day, only some of the blue light is scattered around the sky. Most of the rest of the Sun's light goes straight through the atmosphere, combining to make the familiar yellow-white color of the Sun. (Caution: you should protect your eyes and try to never look directly at the Sun!)

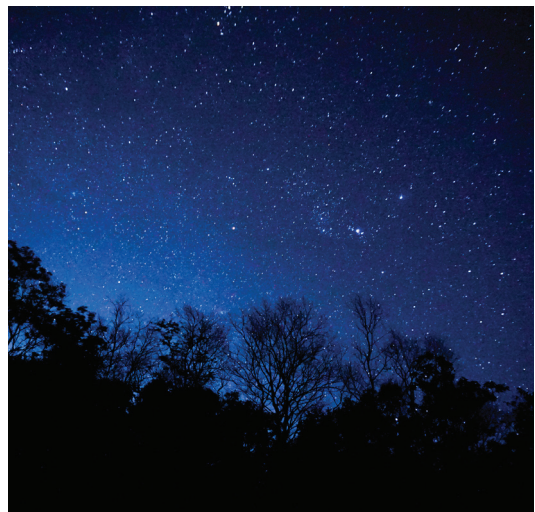


FIGURE 1.10. After the Sun sets and moves further and further below the horizon, fewer and fewer colors are able to scatter widely enough to be seen, until only blue light is left. This means that from about half an hour after sunset, the sky is just ever-darkening shades of blue.

Since red light scatters less easily, the only time we see red in the sky is when the Sun is low in the sky and its light must go through a much thicker section of atmosphere before reaching us (Figure 1.11). This happens around sunset and sunrise (Figure 1.12). At these times, when the Sun is low in the horizon, sunlight passes through up to thirty times more atmosphere than it does at noon.

All the light other than the red is scattered to such a degree that it is lost. Even much of the red light is scattered, causing the sky around the Sun to appear reddish, instead of its usual blue. The remaining red photons from the Sun that are not scattered travel straight through the atmosphere, so the Sun also appears deep red.

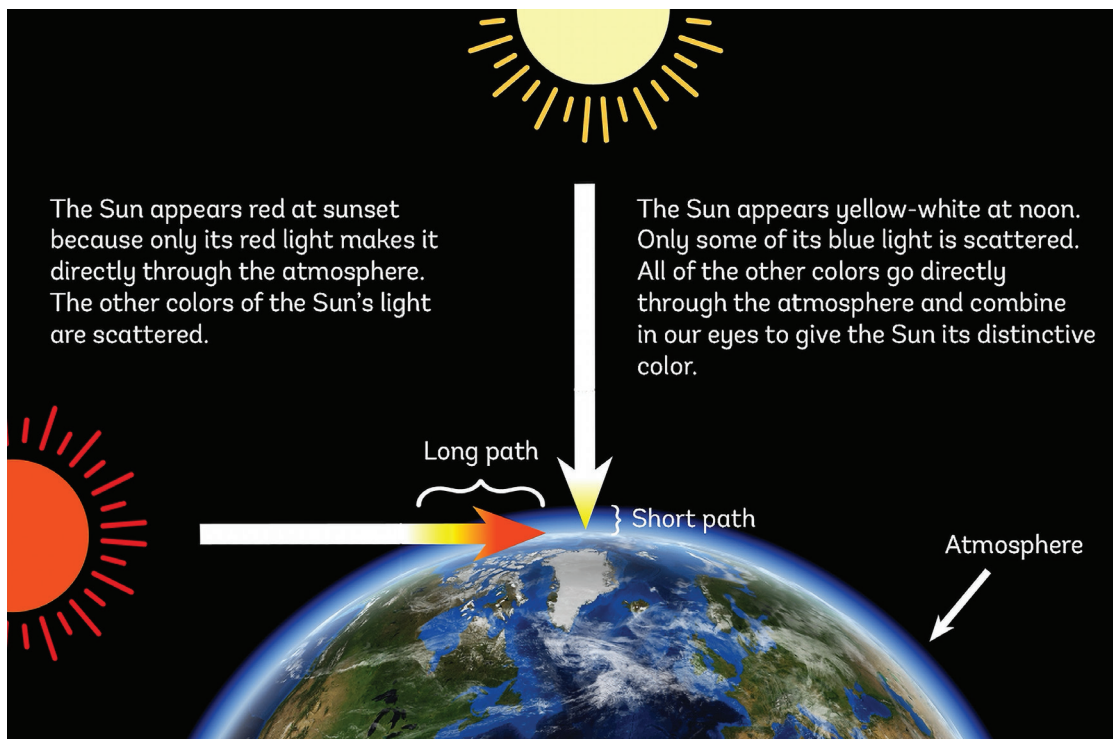


FIGURE 1.11. The Sun's rays must travel through a thicker section of atmosphere at sunrise and sunset (when the Sun appears low in the sky) than they do during the middle of the day.



FIGURE 1.12. The distinctive deep reds of a beautiful sunset