МИНИСТЕРСТВО ОБРАЗОВАНИЯ И НАУКИ
РОССИЙСКОЙ ФЕДЕРАЦИИ

МОСКОВСКИЙ ГОСУДАРСТВЕННЫЙ
УНИВЕРСИТЕТ ГЕОДЕЗИИ И КАРТОГРАФИИ

МЕТОДИЧЕСКИЕ УКАЗАНИЯ

**по английскому языку для студентов I и II курсов
факультета оптико-информационных систем и
технологий
часть I**

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Данное методическое пособие представляет собой сборник оригинальных текстов для формирования навыков просмотрового, ознакомительного и поискового чтения на английском языке. Пособие предназначено для студентов-бакалавров и магистрантов I и II курсов факультета оптико-информационных систем и технологий МИИГАиК.

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Предисловие

Данное методическое пособие по просмотровому, ознакомительному и поисковому чтению текстов на английском языке предназначено для студентов факультета Оптико-информационных систем и технологий МИИГАиК.

Пособие создавалось на основе опыта работы преподавателей кафедры иностранных языков МИИГАиК.

Тексты заимствованы из материалов современной англоязычной литературы.

Задача преподавателя английского языка – сформировать у студентов 1-2 курсов навыки чтения и понимания оригинальной литературы по специальности с целью ее дальнейшего использования в будущей профессии. Умение извлекать необходимую научно-техническую информацию из иностранных источников – условие успешной профессиональной деятельности будущего специалиста.

В пособие включены 5 текстов по оптике на английском языке. Каждому тексту предшествуют предтекстовые задания, нацеливающие студента на поиск требуемой информации.

В конце каждого текста имеется раздел “Discussion Questions”, который содержит вопросы для анализа и оценки понимания изложенного материала. Данный раздел направлен на формирования у студента навыков поиска в тексте необходимой информации и использования ее в дальнейшем при решении новых задач.

После некоторых текстов идут задания под названием “Self-check”, которые дают преподавателю возможность оценить степень понимания прочитанного текста.

В разделе “Selected Vocabulary” дается толкование на английском языке некоторых специальных терминов.

В конце пособия помещен список неправильных глаголов и англо-русский словарь к текстам.

Преподавателю предлагаются следующие виды работы с текстами пособия:

Просмотровое чтение

Просмотровое чтение предполагает получение общего представления о читаемом материале.

В упражнениях по просмотровому чтению целесообразно предложить студенту для анализа более крупные смысловые куски. Задача читающего – понять, представляет ли данный текст интерес, относится ли данный материал к интересующей его теме, стоит ли его читать дальше.

Если после беглого прочтения сделан вывод, что текст интересен, его следует читать дальше с привлечением других видов чтения: поискового, изучающего.

Скорость просмотрового чтения не должна быть ниже 500 слов в минуту. Учебные задания в данном виде чтения направлены на формирование навыков и умений ориентироваться в логико-смысловой структуре текста, умений извлекать и использовать материал текста источника в соответствии с конкретным коммуникативным заданием.

Преподавателю при проведении занятий по выработке навыков просмотрового чтения у студентов рекомендуется использовать следующие виды упражнений:

1. Прочитайте заголовок текста, постарайтесь вникнуть в его смысл, определите главную мысль текста.
2. Прочитайте первый абзац. Сопоставьте его содержание со своим представлением о главной мысли текста.
3. Просмотрите все остальные абзацы, сопоставляя их содержание с представлением главной мысли текста и обращая особое внимание на содержание первых предложений абзацев.
4. Сформулируйте ответ на вопрос:” О чем повествуется в тексте?”
5. Переведите заглавие и ответьте на вопрос: “По какому слову заглавия (или по какому словосочетанию) можно установить, что речь идет о ... ?”
6. Прочтите заглавия текстов. Предположите, о каких конкретных фактах может идти речь в текстах. Просмотрите их.
7. Прочтите заглавие следующего текста и подумайте, с чем оно ассоциируется в вашем представлении. Если заглавие вас интересует, читайте текст дальше.
8. Просмотрите текст. Определите его характер(описание, рассуждение, повествование и т.д.).
9. Просмотрите текст и скажите, содержит ли он с вашей точки зрения интересную информацию.
10. Выделите в тексте вводную, основную и заключительную части.
11. Составьте общее представление о содержании текста по заглавию(таблице, чертежу, рисунку формуле, вводной и заключительной частям).
12. Прочтите первые предложения абзацев и назовите вопросы, которые будут рассматриваться в тексте.
13. Прочтите последний абзац текста и скажите, какое содержание может предшествовать этому выводу.
14. Просмотрите текст, ознакомьтесь с чертежом (рисунком, графиком, таблицей, описываемой в тексте), составьте план основного содержания текста.
15. Ознакомьтесь с графическим изображением в тексте. Затем прочитайте текст и скажите, соответствует ли изображению содержание текста.

16. Установите, какая проблема обсуждается в тексте.
17. Скажите, какая проблема вытекает из содержания текста.
18. Поставьте к тексту несколько вопросов и задайте их вашему товарищу, затем ответьте на его вопросы.
19. Подтвердите точку зрения, изложенную в тексте, используя соответствующий пример.
20. Выскажите ваше мнение о прочитанном, сообщите известные вам дополнительные сведения. Приведите примеры, факты, подобные описываемым в статье.
21. Подумайте, как и где вы можете использовать извлеченную из текста информации.

Ознакомительное чтение

Ознакомительное чтение представляет собой познающее чтение.

Основная коммуникативная задача состоит в том, чтобы в результате быстрого прочтения всего текста извлечь содержащуюся в нем основную информацию, то есть выяснить, какие вопросы и каким образом решаются в тексте, что именно говорится в нем по данным вопросам и т.д. Оно требует умения различать главную и второстепенную информацию.

Для достижения целей ознакомительного чтения бывает достаточно понимания 75% текста. Темп ознакомительного чтения – не ниже 180 слов в минуту.

Для выработки у студентов навыков ознакомительного чтения возможно использование следующих видов упражнений:

1. Прочитайте план(утверждение), обусловьте, соответствует ли он (оно) последовательности изложенных в тексте фактов
2. Составьте план текста.
3. Найдите основную идею сначала, середине и конце текста.
4. Подчеркните в каждом абзаце 1-2 предложения , которые можно было бы опустить как несущественные.
5. Просмотрите текст и озаглавьте его.
6. Перечислите факты, которые вы желали бы уяснить.
7. Составьте аннотацию (лаконичный реферат) прочитанного.
8. Передайте содержание текста в устной (письменной) форме.
9. Составьте выводы на базе прочитанного. Назовите более достойные внимания вопросы (данные), находящиеся в тексте. Укажите, где можно использовать эти сведения.
10. Выскажите свое мировоззрение о возможности использования информации,

содержащейся в тексте, в вашей будущей профессии.

11. Читайте абзац за абзацем, отмечая в каждом из них предложения, несущие главную информацию, и предложения, в которых содержится дополняющая, второстепенная информация.
12. Определите степень важности абзацев, отметьте абзацы, которые содержат более важную информацию, и абзацы, которые содержат второстепенную по значению информацию.
13. Обобщите информацию, выраженную в абзацах в смысловое (единое) целое.
14. Прочтите следующие предложения и назовите союзы (союзные слова), которые используются для связи простых предложений.
15. Разделите текст на смысловые части и озаглавьте каждую часть.
16. Прочтите текст, обратите внимание на чертеж (иллюстрацию) и его заглавие.
17. Прочтите текст и определите тему текста, используя в качестве ориентиров заглавие, фотографии, Термины, интернациональные слова, иллюстрации к чертежу.
18. Прочтите заглавие и первый (последний) абзац текста и скажите, о чем идет речь в тексте.
19. Прочтите текст и скажите, на сколько частей можно условно разделить его, чему посвящена каждая отдельная часть (введение) , постановка проблемы, пути ее решения, выводы и т.д.)
20. Составьте список вопросов к тексту.
21. Подготовьте план пересказа текста.
22. Разделите текст на смысловые части и озаглавьте их.
23. Сравните точки зрения, изложенные в тексте.
24. Сформулируйте идею текста.
25. Прочтите текст, отметьте факты, на основании которых автор делает главные выводы.
26. Сократите текст за счет подробностей, которые могут быть опущены без ущерба для содержания.
27. Поясните главную мысль текста своими словами.
28. Выразите свое отношение к прочитанному. Скажите, согласны ли вы с оценкой автором событий, фактов.
29. Прочитайте вслух предложения, которые объясняют заглавие текста.
30. Скажите, с каким из изложенных положений текста вы не согласны и почему.
31. Скажите, какие из перечисленных фактов вы узнали впервые из прочитанного

текста.

32. Скажите, при изучении каких предметов вам может понадобиться информация, содержащаяся в данном тексте.
33. Поясните, в чем вы видите расхождения в подходе автора данного текста и авторов учебника, которым вы пользуетесь.
34. Назовите, какие публикации по этой проблеме вы читали.
35. Составьте вопросы, по которым вы хотели бы получить информацию по теме из литературы, изданной за рубежом.

Поисковое чтение.

Цель поискового чтения – быстрое нахождение в тексте вполне определенных данных (фактов, характеристик, цифровых показателей, указаний). Оно направлено на нахождение в тексте конкретной информации. Студенту известно из других источников, что такая информация содержится в данной статье (книге), поэтому он сразу же обращается к определенным разделам, которые и повергает изучающему чтению без детального анализа.

Такое чтение, как и просмотровое, предполагает наличие умения ориентироваться в логико- смысловой структуре текста, выбрать из него необходимую информацию по определенной проблеме, выбрать и объединить информацию нескольких текстов по отдельным вопросам.

Упражнения, рекомендуемые для обучения поисковому чтению:

1. Обусловьте тему (дилемму) текста (статьи).
2. Найдите абзацы, посвященные обозначенной теме.
3. Найдите в тексте факты, которые автор относит к положительным (отрицательным).
4. Разделите текст на части в согласовании с пунктами плана.
5. Выразите свое мировоззрение о содержании текста и сопоставьте его со своим опытом.
6. Просмотрите текст и скажите, для какой категории читателей он может представлять интерес и почему.
7. Просмотрите текст, найдите его фрагмент, который представляет для вас особый интерес, и объясните, почему.
8. Скажите, какому из указанных вопросов уделяется в статье особое внимание.
9. Просмотрите предложенные вам тексты и подберите из них факты, которые относятся к теме ... , (которые могли бы служить иллюстрацией к тезису, утверждению ...).

10. Укажите в тексте абзацы, в которых содержатся данные о ... .
11. Найдите в статье определение (выводы, формулировку проблемы; термин, обозначающий...) и зачитайте вслух.
12. Найдите в тексте факты, упомянутые в аннотации (резюме).
13. Отметьте в тексте места, дающие ответы на предложенные вопросы.
14. Найдите в тексте факты, которые дают основание сделать выводы, составить тезисы.
15. Найдите и отметьте в тексте места, относящиеся к ... (характеризующие ...).
16. Зачитайте вслух из текста факты, которые относятся к теме... .
17. Подчеркните в тексте определение (вывод, формулировку проблемы; термин, обозначающий ...).

При обнаружении искомой информации цель поискового чтения достигнута; чтение следует прекратить, либо перейти к другим его видам (ознакомительному, изучающему).

АВТОРЫ ПРЕДПОЛАГАЮТ, ЧТО УКАЗАННЫЙ СПИСОК УПРАЖНЕНИЙ НЕ ЯВЛЯЕТСЯ ИСЧЕРПЫВАЮЩИМ И ПРЕПОДАВАТЕЛЬ МОЖЕТ САМ РАСШИРЯТЬ И ДОПОЛНЯТЬ ЕГО В ЗАВИСИМОСТИ ОТ ПОСТАВЛЕННОЙ ЦЕЛИ УРОКА. ГЛАВНАЯ ЗАДАЧА – ФОРМИРОВАНИЕ НАВЫКОВ И УМЕНИЙ В РАЗЛИЧНЫХ ВИДАХ ЧТЕНИЯ, ЧТО ПОЗВОЛИТ СТУДЕНТУ В ДАЛЬНЕЙШЕМ ЗАНИМАТЬСЯ САМООБРАЗОВАНИЕМ, СОВЕРШЕНСТВУЯСЬ В СВОЕЙ СПЕЦИАЛЬНОСТИ.

Текст 1

Задание

Найдите в Тексте 1 ответы на следующие вопросы:

1. How did Pythagoras explain the phenomenon of seeing?
2. What provides the simplest evidence of human precedence over natural phenomena in seeing?
3. How does Newtonian physics explain the propagation of light?
4. Who was the first to measure the speed of light?
5. How can it be proved that light travels in vacuum?

The Nature of Light

The cause and effect relationship in vision

In ancient times, even smart people who have thought hard about vision have come up with incorrect ideas about light and vision. The ancient Greeks, Arabs and Chinese had theories of light and vision, all of which were mostly wrong, and all of which were accepted for thousands of years.

One thing the ancients did get right is that there is a distinction between objects that emit light and objects that don't. When you see a leaf in the forest, it's because three different objects are doing their jobs: the leaf, the eye, and the sun. But luminous objects like the sun, a flame, or the filament of a light bulb can be seen by the eye without the presence of a third object. Emission of light is often, but not always, associated with heat. In modern times, we are familiar with a variety of objects that glow without being heated, including fluorescent lights and glow-in-the-dark toys.

How do we see luminous objects? The Greek philosophers Pythagoras (b. ca. 560 BC) and Empedocles of Acragas (b. ca. 492 BC), who unfortunately were very influential, claimed* that when you looked at a candle flame, the flame and your eye were both sending out some kind of mysterious stuff , and when your eye's stuff collided with the candle's stuff, the candle would become evident to your sense of sight.

Bizarre as the Greek "collision of stuff theory" might seem, it had a couple of good features. It explained why both the candle and your eye had to be present for your sense of sight to function. The theory could also easily be expanded to explain how we see nonluminous objects. If a leaf, for instance, happened to be present at the site of the collision between your eye's stuff and the candle's stuff, then the leaf would be stimulated to express its green nature, allowing you to perceive it as green.

1801 Modern people might feel uneasy about this theory, since it suggests that greenness exists only for our seeing convenience, implying a human precedence over natural phenomena. Nowadays, people would expect the cause and effect relationship in vision to be the other way around, with the leaf doing something to our eye rather than our eye doing something to the leaf. But how can you tell? The most common way of distinguishing cause from effect is to determine which happened first, but the process of seeing seems to occur too quickly to determine the order in which things happened. Certainly there is no obvious time lag between the moment when you move your head and the moment when your reflection in the mirror moves.

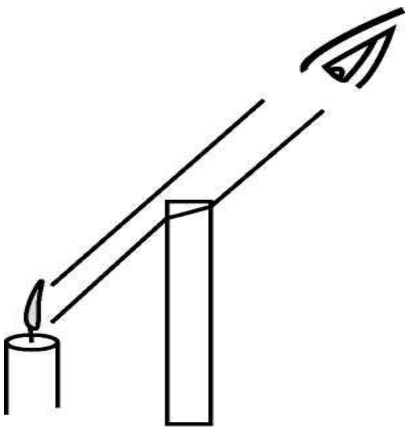
Today, photography provides the simplest experimental evidence that nothing has to be emitted from your eye and hit the leaf in order to make it "greenify." A camera can take a picture of a leaf even if there are no eyes anywhere nearby. Since the leaf appears green regardless of whether it is being sensed by a camera, your eye, or an insect's eye, it seems to make more sense to say that the leaf's greenness is the cause, and something happening in the camera or eye is the effect.

1209

Light is a thing, and it travels from one point to another.

Another issue that few people have considered is whether a candle's flame simply affects your eye directly, or whether it sends out light which then gets into your eye.

Again, the rapidity of the effect makes it difficult to tell what's happening. If someone throws a rock at you, you can see the rock on its way to your body, and you can tell that the person affected you by sending a material substance your way, rather than just harming you directly with an arm motion, which would be known as "action at a distance." It is not easy to do a similar observation to see whether there is some "stuff" that travels from the candle to your eye, or whether it is a case of action at a distance.



a) Light from a candle is bumped off course by a piece of glass. Inserting the glass causes the apparent location of the candle to shift. The same effect can be produced by taking off your eyeglasses and looking at which you see near the edge of the lens, but a flat piece of glass works just as well as a lens for this purpose.

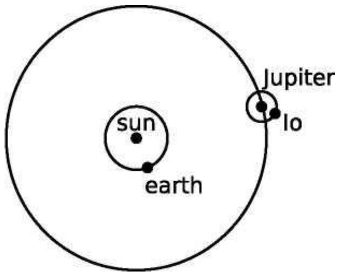
Newtonian physics includes both action at a distance (e.g. the earth's gravitational force on a falling object) and contact forces such as the normal force, which only allow distant objects to exert forces on each other by shooting some substance across the space between them (e.g., a garden hose spraying out water that exerts a force on a bush).

One piece of evidence that the candle sends out stuff that travels to your eye is that as in figure a), intervening transparent substances can make the candle appear to be in the wrong location, suggesting that light is a thing that can be bumped off course. Many people would dismiss this kind of observation as an optical illusion, however. (Some optical illusions are purely neurological or psychological effects, although some others, including this one, turn out to be caused by the behavior of light itself.)

A more convincing way to decide in which category light belongs is to find out if it takes time to get from the candle to your eye; in Newtonian physics, action at a distance is supposed to be instantaneous. The fact that we speak casually today of "the speed of light" implies that at some point in history, somebody succeeded in showing that light did not travel infinitely fast. Galileo tried, and failed, to detect a finite speed for light, by arranging with a person in a distant tower to signal back and forth with lanterns.

2143 Galileo uncovered his lantern, and when the other person saw the light, he uncovered his lantern. Galileo was unable to measure any time lag that was significant compared to the limitations of human reflexes. The first person to prove that light's speed was finite, and to determine it numerically, was Ole Roemer, in a series of measurements around the year 1675. Roemer observed Io, one of Jupiter's moons, over a period of several years. Since Io presumably took the same amount of time to complete each orbit of Jupiter, it could be thought of as a very distant, very accurate clock. A practical and accurate pendulum clock had recently been invented, so Roemer could check whether the ratio of the two clocks' cycles, about 42.5 hours to 1 orbit, stayed exactly constant or changed a little. If the process of seeing the distant moon was instantaneous, there would be no reason for the two to get out of step. Even if the speed of light was finite, you might expect that the result would be only to offset one cycle relative to the other.

b) An image of Jupiter and its moon Io (left) from Cassini probe.



c) The earth is moving toward Jupiter and Io. Since the distance is shrinking, it is taking less and less time for the light to get to us from Io, and Io appears to circle Jupiter more quickly than normal. Six months later, the earth will be on the opposite side of the sun, and receding from Jupiter and Io, so Io will appear to revolve around Jupiter more slowly.

The earth does not, however, stay at a constant distance from Jupiter and its moons. Since the distance is changing gradually due to the two planets' orbital motions, a finite speed of light would make the "Io clock" appear to run faster as the planets drew near each other, and more slowly as their separation increased.

Roemer did find a variation in the apparent speed of Io's orbits, which caused Io's eclipses by Jupiter (the moments when Io passed in front of or behind Jupiter) to occur about 7 minutes early when the earth was closest to Jupiter, and 7 minutes late when it was farthest. Based on these measurements, Roemer estimated the speed of light to be approximately 2 x 10^8 m/s, which is in the right ballpark compared to modern measurements of 3 x 10^8 m/s. (I'm not sure whether the fairly large experimental error was mainly due to imprecise knowledge of the radius of the earth's orbit or limitations in the reliability of pendulum clocks.)

2000

Light can travel through a vacuum.

Many people are confused by the relationship between sound and light. Although we use different organs to sense them, there are some similarities. For instance, both light and sound are typically emitted in all directions by their sources. Musicians even use visual metaphors like "tone color," or "a bright timbre" to describe sound. One way to see that they are clearly different phenomena is to note their very different velocities. Sure, both are pretty fast compared to a flying arrow or a galloping horse, but as we have seen, the speed of light is so great as to appear instantaneous in most situations. The speed of sound, however, can easily be observed just by watching a group of schoolchildren a hundred feet away as they clap their hands to a song. There is an obvious delay between when you see their palms come together and when you hear the clap.

The fundamental distinction between sound and light is that sound is an oscillation in air pressure, so it requires air (or some other medium such as water) in which to travel. Today, we know that outer space is a vacuum, so the fact that we get light from the sun, moon and stars
1249 clearly shows that air is not necessary for the propagation of light.

Discussion Questions

A If you observe thunder and lightning, you can tell how far away the storm is. Do you need to know the speed of sound, of light, or of both?

B When phenomena like X-rays and cosmic rays were first discovered, suggest a way one could have tested whether they were forms of light.

C Why did Roemer only need to know the radius of the earth's orbit, not Jupiter's, in order to find the speed of light?

Текст 2

Задание

Найдите в Тексте 2 ответы на следующие вопросы:

1. Is heating by absorption any different from heating by thermal conduction?
2. Is light reflected from the book you read?
3. What’s the difference between specular and diffuse reflections?
4. How does brightness of light relate to power of light?
5. Why are bright lines shooting out of a laser gun in science fiction movies scientifically incorrect?

Interaction of Light with Matter

Absorption of light

The reason why the sun feels warm on your skin is that the sunlight is being absorbed, and the light energy is being transformed into heat energy. The same happens with artificial light, so the net result of leaving a light turned on is to heat the room. It doesn't matter whether the source of the light is hot, like the sun, a flame, or an incandescent light bulb, or cool, like a fluorescent bulb. (If your house has electric heat, then there is absolutely no point in fastidiously turning off lights in the winter; the lights will help to heat the house at the same dollar rate as the electric heater.)

This process of heating by absorption is entirely different from heating by thermal conduction, as when an electric stove heats spaghetti sauce through a pan. Heat can only be conducted through matter, but there is vacuum between us and the sun, or between us and the filament of an incandescent bulb. Also, heat conduction can only transfer heat energy from a hotter object to a colder one, but a cool fluorescent bulb is perfectly capable of heating something that had already started out being warmer than the bulb itself.

How we see nonluminous objects

Not all the light energy that hits an object is transformed into heat. Some is reflected, and this leads us to the question of how we see nonluminous objects. If you ask the average person how we see a light bulb, the most likely answer is "The light bulb makes light, which hits our eyes." But if you ask how we see a book, they are likely to say "The bulb lights up the room, and that lets me see the book." All mention of light actually entering our eyes has mysteriously disappeared.

Most people would disagree if you told them that light was reflected from the book to the eye, because they think of reflection as something that mirrors do, not something that a book does. They associate reflection with the formation of a reflected image, which does not seem to appear in a piece of paper.

2006 Imagine that you are looking at your reflection in a nice smooth piece of aluminum foil, fresh off the roll. You perceive a face, not a piece of metal. Perhaps you also see the bright reflection of a lamp over your shoulder behind you. Now imagine that the foil is just a little bit less smooth. The different parts of the image are now a little bit out of alignment with each other. Your brain can still recognize a face and a lamp, but it's a little scrambled, like a Picasso painting.

Now suppose you use a piece of aluminum foil that has been crumpled up and then flattened out again. The parts of the image are so scrambled that you cannot recognize an image. Instead, your brain tells you you're looking at a rough, silvery surface.

Mirror-like reflection at a specific angle is known as specular reflection, and random reflection in many directions is called diffuse reflection. Diffuse reflection is how we see nonluminous objects. Specular reflection only allows us to see images of objects other than the one doing the reflecting. In top part of figure d), imagine that the rays of light are coming from the sun. If you are looking down at the reflecting surface, there is no way for your eye-brain system to tell that the rays are not really coming from a sun down below you.

Figure f) shows another example of how we can't avoid the conclusion that light bounces off of things other than mirrors. The lamp is one I have in my house. It has a bright bulb, housed in a completely opaque bowl-shaped metal shade.

The only way light can get out of the lamp is by going up out of the top of the bowl. The fact that I can read a book in the position shown in the figure means that light must be bouncing off of the ceiling, then bouncing off of the book, and then finally getting to my eye.

This is where the shortcomings of the Greek theory of vision become glaringly obvious. In the Greek theory, the light from the bulb and my mysterious "eye rays" are both supposed to go to the book, where they collide, allowing me to see the book. But we now have a total of four objects: lamp, eye, book, and ceiling. Where does the ceiling come in? Does it also send out its own mysterious "ceiling rays," contributing to a three-way collision at the book? That would just be too bizarre to believe!

The differences among white, black, and the various shades of gray in between is a matter of what percentage of the light they absorb and what percentage they reflect. That's why light-colored clothing is more comfortable in the summer, and light-colored upholstery in a car stays cooler that dark upholstery.

d) Two self-portraits of the author, one taken in a mirror and one with a piece of aluminum foil.

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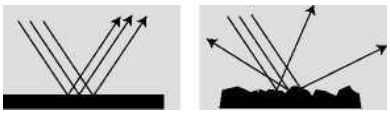
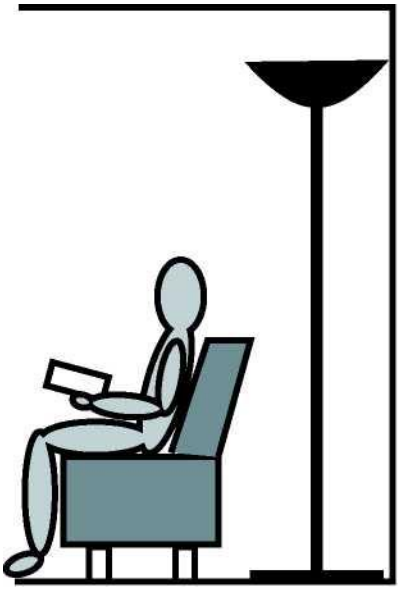


e) Specular and diffuse reflection



f) Light bounces off of the ceiling, then off of the book.

Numerical measurement of the brightness of light

We have already seen that the physiological sensation of loudness relates to the sound's intensity (power per unit area), but is not directly proportional to it. If sound A has an intensity of 1 nW/m^2, sound B is 10 nW/m^2, and sound C is 100 nW/m^2, then the increase in loudness from C to B is perceived to be the same as the increase from A to B, not ten times greater. That is, the sensation of loudness is logarithmic.

The same is true for the brightness of light. Brightness is related to power per unit area, but the psychological relationship is a logarithmic one rather than a proportionality. For doing physics, it's the power per unit area that we're interested in. The relevant unit is W/m^2. One way to determine the brightness of light is to measure the increase in temperature of a black object exposed to the light.

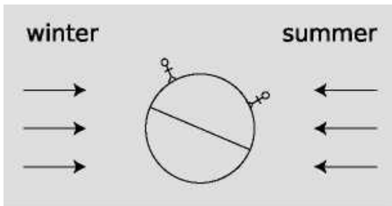
The light energy is being converted to heat energy, and the amount of heat energy absorbed in a given amount of time can be related to the power absorbed, using the known heat capacity of the object. More practical devices for measuring light intensity, such as the light meters built into some cameras, are based on the conversion of light into electrical energy, but these meters have
2123 to be calibrated somehow against heat measurements.

Discussion Questions

A Curtains in a room are drawn, but a small gap lets light through, illuminating a spot on the floor. It may or may not also be possible to see the beam of sunshine crossing the room, depending on the conditions. What's going on?

B Laser beams are made of light. In science fiction movies, laser beams are often shown as bright lines shooting out of a laser gun on a spaceship. Why is this scientifically incorrect?

C A documentary film-maker went to Harvard's 1987 graduation ceremony and asked the graduates, on camera, to explain the cause of the seasons. Only two out of 23 were able to give a correct explanation, but you now have all the information needed to figure it out for yourself, assuming you didn't already know. The figure shows the earth in its winter and summer positions relative to the sun. Hint: Consider the units used to measure the brightness of light, and recall that the sun is lower in the sky in winter, so its rays are coming in at a shallower angle.



g) Discussion question C

Текст 3

Задание

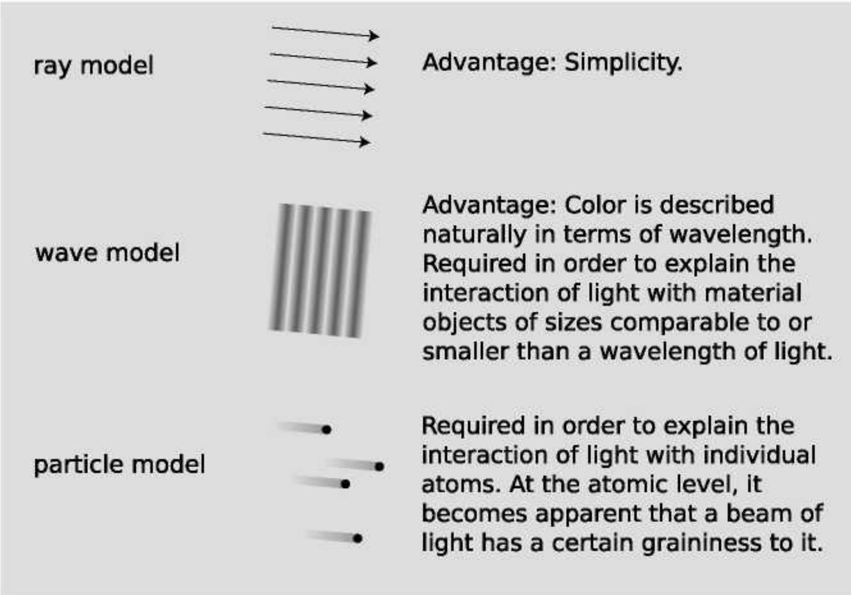
Найдите в Тексте 3 ответы на следующие вопросы:

1. Is the ray model the only one to describe light?
2. When are the wave and the particle models of light required?
3. Do electric and magnetic fields deflect light beams?
4. Who predicted that light would be deflected by gravitational fields?
5. What is time-reversal symmetry characteristic of?

The Ray Model of Light

Models of light

Note how I've been casually diagramming the motion of light with pictures showing light rays as lines on the page. More formally, this is known as the ray model of light. The ray model of light seems natural once we convince ourselves that light travels through space, and observe phenomena like sunbeams coming through holes in clouds. Having already been introduced to the concept of light as an electromagnetic wave, you know that the ray model is not the ultimate truth about light, but the ray model is simpler, and in any case science always deals with models of reality, not the ultimate nature of reality. The following table summarizes three models of light.



h) Three models of light

The ray model is a generic one. By using it we can discuss the path taken by the light, without committing ourselves to any specific description of what it is that is moving along that path. We will use the nice simple ray model for most of this book, and with it we can analyze a great many devices and phenomena. Not until the last chapter will we concern ourselves specifically with wave optics, although in the intervening chapters I will sometimes analyze the same phenomenon using both the ray model and the wave model.

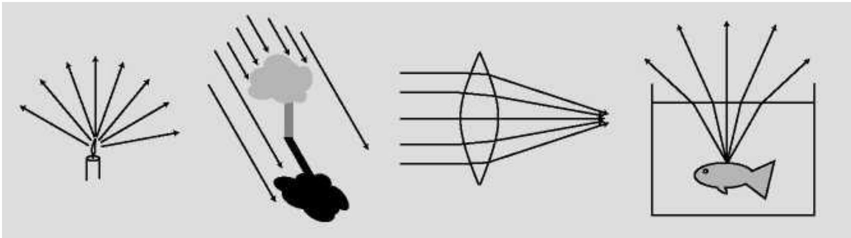
Note that the statements about the applicability of the various models are only rough guides. For instance, wave interference effects are often detectable, if small, when light passes around an obstacle that is quite a bit bigger than a wavelength. Also, the criterion for when we need the particle model really has more to do with energy scales than distance scales, although the two turn out to be related.

The alert reader may have noticed that the wave model is required at scales smaller than a wavelength of light (on the order of a micrometer for visible light), and the particle model is demanded on the atomic scale or lower (a typical atom being a nanometer or so in size). This implies that at the smallest scales we need *both* the wave model and the particle model. They appear incompatible, so how can we simultaneously use both? The answer is that they are not as incompatible as they seem. Light is both a wave and a particle, but a full understanding of this apparently nonsensical statement is a topic for the following book.

2269

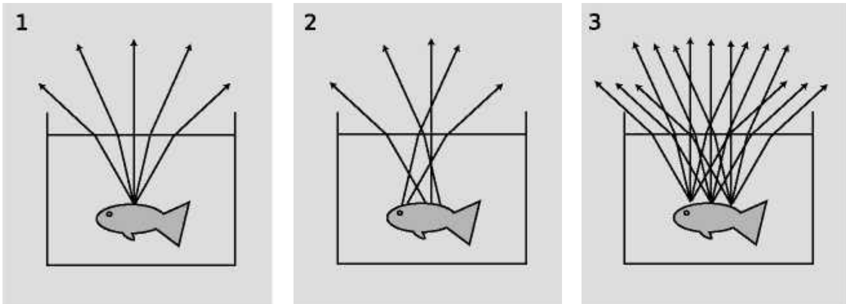
Ray diagrams

Without even knowing how to use the ray model to calculate anything numerically, we can learn a great deal by drawing ray diagrams. For instance, if you want to understand how eyeglasses help you to see in focus, a ray diagram is the right place to start. Many students under-utilize ray diagrams in optics and instead rely on rote memorization or plugging into formulas. The trouble with memorization and plug-ins is that they can obscure what's really going on, and it is easy to get them wrong. Often the best plan is to do a ray diagram first, then do a numerical calculation, then check that your numerical results are in reasonable agreement with what you expected from the ray diagram.



i) Examples of ray diagrams.

Figure j) shows some guidelines for using ray diagrams effectively. The light rays bend when they pass out through the surface of the water (a phenomenon that we'll discuss in more detail later). The rays appear to have come from a point above the goldfish's actual location, an effect that is familiar to people who have tried spear-fishing.



j) 1. Correct.
2. Incorrect: implies that diffuse reflection only gives one ray from each reflecting point.
3. Correct, but unnecessarily complicated

- A stream of light is not really confined to a finite number of narrow lines. We just draw it that way. In j)1, it has been necessary to choose a finite number of rays to draw (five), rather than the theoretically infinite number of rays that will diverge from that point.
- There is a tendency to conceptualize rays incorrectly as objects. In his Optics, Newton goes out of his way to caution the reader against this, saying that some people "consider ... the refraction of ... rays to be the bending or breaking of them in their passing out of one medium into another." But a ray is a record of the path traveled by light, not a physical thing that can be bent or broken.

• In theory, rays may continue infinitely far into the past and future, but we need to draw lines of finite length. In j)1, a judicious choice has been made as to where to begin and end the rays. There is no point in continuing the rays any farther than shown, because nothing new and exciting is going to happen to them. There is also no good reason to start them earlier, before being reflected by the fish, because the direction of the diffusely reflected rays is random anyway, and unrelated to the direction of the original, incoming ray.

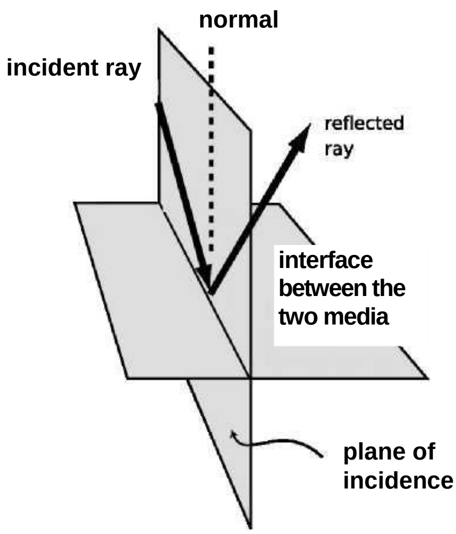
• When representing diffuse reflection in a ray diagram, many students have a mental block against drawing many rays fanning out from the same point. Often, as in example j)2, the problem is the misconception that light can only be reflected in one direction from one point.

• Another difficulty associated with diffuse reflection, example j)3, is the tendency to think that in addition to drawing many rays coming out of one point, we should also be drawing many rays coming from many points. In j)1, drawing many rays coming out of one point gives useful information, telling us, for instance, that the fish can be seen from any angle. Drawing many sets of rays, as in j)3, does not give us any more useful information, and just clutters up the picture in this example. The only reason to draw sets of rays fanning out from
3175 more than one point would be if different things were happening to the different sets.

Discussion Question

A Suppose an intelligent tool-using fish is spear-hunting for humans. Draw a ray diagram to show how the fish has to correct its aim. Note that although the rays are now passing from the air to the water, the same rules apply: the rays are closer to being perpendicular to the surface when they are in the water, and rays that hit the air-water interface at a shallow angle are bent the most.

Geometry of Specular Reflection



k) The geometry of specular reflection

To change the motion of a material object, we use a force. Is there any way to exert a force on a beam of light? Experiments show that electric and magnetic fields do not deflect light beams, so apparently light has no electric charge. Light also has no mass, so until the twentieth century it was believed to be immune to gravity as well. Einstein predicted that light beams would be very slightly deflected by strong gravitational fields, and he was proved correct by observations of rays of starlight that came close to the sun, but obviously that's not what makes mirrors and lenses work!

If we investigate how light is reflected by a mirror, we will find that the process is horrifically complex, but the final result is surprisingly simple. What actually happens is that the light is made of electric and magnetic fields, and these fields accelerate the electrons in the mirror. Energy from the light beam is momentarily transformed into extra kinetic energy of the electrons, but because the electrons are accelerating they re-radiate more light, converting their kinetic energy back into light energy.

We might expect this to result in a very chaotic situation, but amazingly enough, the electrons move together to produce a new, reflected beam of light, which obeys two simple rules:

- The angle of the reflected ray is the same as that of the incident ray.
- The reflected ray lies in the plane containing the incident ray and the normal (perpendicular) line. This plane is known as the plane of incidence.

The two angles can be defined either with respect to the normal, like angles B and C in the figure, or with respect to the reflecting surface, like angles A and D.

There is a convention of several hundred years' standing that one measures the angles with respect to the normal, but the rule about equal angles can logically be stated either as B=C or as A=D.

The phenomenon of reflection occurs only at the boundary between two media, just like the change in the speed of light that passes from one medium to another. As we know, this is the way all waves behave.

Most people are surprised by the fact that light can be reflected back from a less dense medium. For instance, if you are diving and you look up at the surface of the water, you will see a reflection of yourself.

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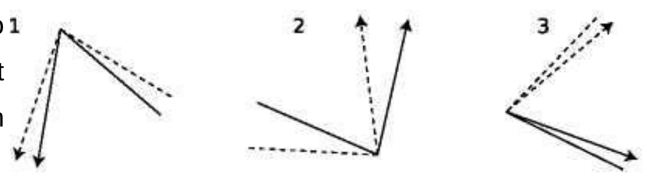
self-check A

Each of these diagrams is supposed to show two different rays being reflected from the same point on the same mirror. Which are correct, and which are incorrect?



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eversibility of light rays

The fact that specular reflection displays equal angles of incidence and reflection means that there is symmetry: if the ray had come in from the right instead of the left in the figure above, the angles would have looked exactly the same. This is not just a pointless detail about specular reflection. It's a manifestation of a very deep and important fact about nature, which is that the laws of physics do not distinguish between past and future. Cannonballs and planets have trajectories that are equally natural in reverse, and so do light rays. This type of symmetry is called time-reversal symmetry.

Typically, time-reversal symmetry is a characteristic of any process that does not involve heat. For instance, the planets do not experience any friction as they travel through empty space, so there is no frictional heating. We should thus expect the time-reversed versions of their orbits to obey the laws of physics, which they do. In contrast, a book sliding across a table does generate heat from friction as it slows down, and it is therefore not surprising that this type of motion does not appear to obey time-reversal symmetry. A book lying still on a flat table is never observed to spontaneously start sliding, sucking up heat energy and transforming it into kinetic energy.

Similarly, the only situation we've observed so far where light does not obey time-reversal symmetry is absorption, which involves heat. Your skin absorbs visible light from the sun and heats up, but we never observe people's skin to glow, converting heat energy into visible light. People's skin does glow in infrared light, but that doesn't mean the situation is symmetric. Even if you absorb infrared, you don't emit visible light, because your skin isn't hot enough to glow in the visible spectrum.

These apparent heat-related asymmetries are not actual asymmetries in the laws of physics. The interested reader may wish to learn more about this from the optional thermodynamics chapter of book 2 in this series.

2034 ***Ray tracing on a computer (example 1)***

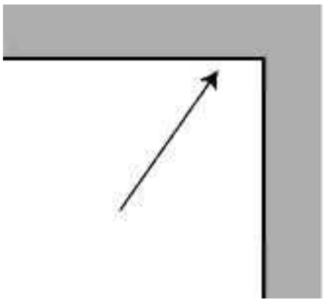
A number of techniques can be used for creating artificial visual scenes in computer graphics. Figure l) shows such a scene, which was created by the brute-force technique of simply constructing a very detailed ray diagram on a computer. This technique requires a great deal of computation, and is therefore too slow to be used for video games and computer-animated movies. One trick for speeding up the computation is to exploit the reversibility of light rays. If one was to trace every ray emitted by every illuminated surface, only a tiny fraction of those would actually end up passing into the virtual "camera," and therefore almost all of the computational effort would be wasted. One can instead start a ray at the camera, trace it backward in time, and see where it would have come from. With this technique, there is no
882 wasted effort.

Discussion Questions

l) This photorealistic image of a nonexistent countertop was produced completely on a computer, by computing a complicated ray diagram.

A If a light ray has a velocity vector with components c_x and c_y, what will happen when it is reflected from a surface that lies along the y axis? Make sure your answer does not imply a change in the ray's speed.

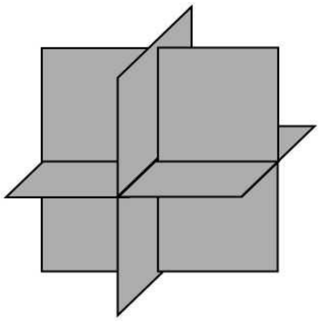
B Generalizing your reasoning from discussion question A, what will happen to the velocity components of a light ray that hits a corner, as shown in the figure, and undergoes two reflections?



m) Discussion question B.

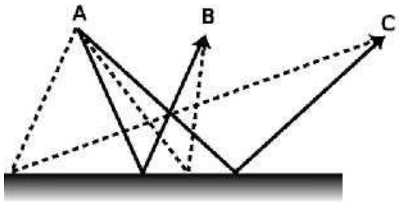
C Three pieces of sheet metal arranged perpendicularly as shown in the figure form what is known as a radar corner. Let's assume that the radar corner is large compared to the wavelength of the radar waves, so that the ray model makes sense. If the radar corner is bathed in radar rays, at least some of them will undergo three reflections.

Making a further generalization of your reasoning from the two preceding discussion questions, what will happen to the three velocity components of such a ray? What would the radar corner be useful for?

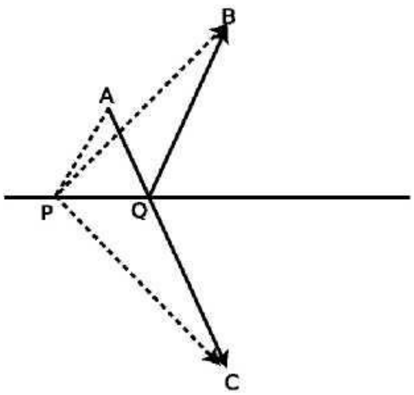


n) Discussion question C.

The Principle of Least Time for Reflection



o) The solid lines are physically possible paths for light rays traveling from A to B and from A to C They obey the principle of least time. The dashed lines do not obey the principle of least time, and are not physically possible.



p) Paths AQB and APB are two conceivable paths that a ray could follow to get from A to B with one reflection, but only AQB is physically possible. We wish to prove that the path AQB, with equal angles of incidence and reflection, is shorter than any other path, such as APB. The trick is to construct a third point, C, lying as far below the surface as B lies above it. Then path AQC is a straight line whose length is the same as AQB's, and path APC has the same length as path APB. Since AQC is straight, it must be shorter than any other path such as APC that connects A and C, and therefore AQB must be shorter than any path such as APB.

We had to choose between an unwieldy explanation of reflection at the atomic level and a simpler geometric description that was not as fundamental. There is a third approach to describing the interaction of light and matter which is very deep and beautiful. Emphasized by the twentieth-century physicist Richard Feynman, it is called the principle of least time, or Fermat's principle.

Let's start with the motion of light that is not interacting with matter at all. In a vacuum, a light ray moves in a straight line.

This can be rephrased as follows: of all the conceivable paths light could follow from P to Q, the only one that is physically possible is the path that takes the least time.

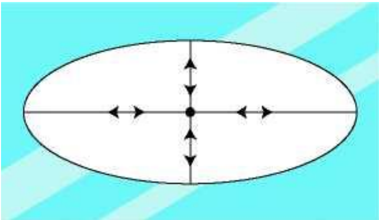
What about reflection? If light is going to go from one point to another, being reflected on the way, the quickest path is indeed the one with equal angles of incidence and reflection. If the starting and ending points are equally far from the reflecting surface, o), it's not hard to convince yourself that this is true, just based on symmetry. There is also a tricky and simple proof, shown in figure p), for the more general case where the points are at different distances from the surface.

Not only does the principle of least time work for light in a vacuum and light undergoing reflection, we will also see in a later chapter that it works for the bending of light when it passes from one medium into another.

Although it is beautiful that the entire ray model of light can be reduced to one simple rule, the principle of least time, it may seem a little spooky to speak as if the ray of light is intelligent, and has carefully planned ahead to find the shortest route to its destination. How does it know in advance where it's going? What if we moved the mirror while the light was en route, so conditions along its planned path were not what it "expected?" The answer is that the principle of least time is really a shortcut for finding certain results of the wave model of light, which is the topic of the last chapter of this book.

There are a couple of subtle points about the principle of least time. First, the path does not have to be the quickest of all possible paths; it only needs to be quicker than any path that differs infinitesimally from it. In figure p), for instance, light could get from A to B either by the reflected path AQB or simply by going straight from A to B.

Although AQB is not the shortest possible path, it cannot be shortened by changing it infinitesimally, e.g., by moving Q a little to the right or left. On the other hand, path APB is physically impossible, because it is possible to improve on it by moving point P infinitesimally to the right.



q) Light is emitted at the center of an elliptical mirror. There are four physically possible paths by which a ray can be reflected and return to the center.

1076

It's not quite right to call this the principle of *least* time. In figure q), for example, the four physically possible paths by which a ray can return to the center consist of two shortest-time paths and two longest-time paths. Strictly speaking, we should refer to the *principle of least or greatest time*, but most physicists omit the niceties, and assume that other physicists understand that both maxima and minima are possible.

Selected Vocabulary

Absorption .... what happens when light hits matter and gives up some of its energy

Reflection .... what happens when light hits matter and bounces off, retaining at least some of its energy

specular reflection .... reflection from a smooth surface, in which the light ray leaves at the same angle at which it came in

diffuse reflection................. reflection from a rough surface, in which a single ray of light is divided up into many weaker reflected rays going in many directions

normal................................. the line perpendicular to a surface at a given point

Notation

C .... the speed of light

Summary

We can understand many phenomena involving light without having to use sophisticated models such as the wave model or the particle model. Instead, we simply describe light according to the path it takes, which we call a ray. The ray model of light is useful when light is interacting with material objects that are much larger than a wavelength of light. Since a wavelength of visible light is so short compared to the human scale of existence, the ray model is useful in many practical cases.

We see things because light comes from them to our eyes. Objects that glow may send light directly to our eyes, but we see an object that doesn't glow via light from another source that has been reflected by the object.

Many of the interactions of light and matter can be understood by considering what happens when light reaches the boundary between two different substances. In this situation, part of the light is reflected (bounces back) and part passes on into the new medium. This is not surprising — it is typical behavior for a wave, and light is a wave. Light energy can also be absorbed by matter, i.e., converted into heat.

A smooth surface produces specular reflection, in which the reflected ray exits at the same angle with respect to the normal as that of the incoming ray. A rough surface gives diffuse reflection, where a single
1428 ray of light is divided up into many weaker reflected rays going in many directions.

Narcissus, by Michelangelo Caravaggio, ca. 1598.

Текст 4

Задание

Найдите в Тексте 4 ответы на следующие вопросы:

1. Is the shortest comfortable eye-mirror distance equal to the shortest comfortable eye-paper distance?
2. What do they mean when they say that there's an image behind the mirror?
3. What is the basic building block of all optical devices?
4. What is the mirror, converging rays, called?
5. What is the difference between a virtual image and a real one?

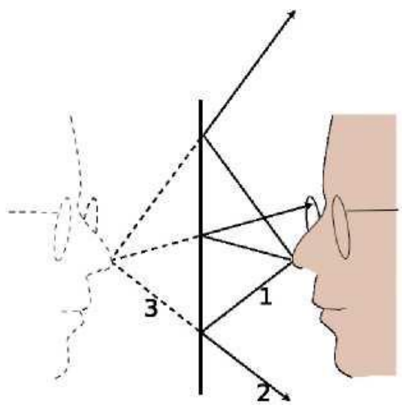
Images by Reflection

Infants are always fascinated by the antics of the Baby in the Mirror. Now if you want to know something about mirror images that most people don't understand, try this. First bring this page closer and closer to your eyes, until you can no longer focus on it without straining. Then go in the bathroom and see how close you can get your face to the surface of the mirror before you can no longer easily focus on the image of your own eyes. You will find that the shortest comfortable eye-mirror distance is much less than the shortest comfortable eye-paper distance. This demonstrates that the image of your face in the mirror acts as if it had depth and existed in the space *behind* the mirror. If the image was like a flat picture in a book, then you wouldn't be able to focus on it from such a short distance.

In this chapter we will study the images formed by flat and curved mirrors on a qualitative, conceptual basis. Although this type of image is not as commonly encountered in everyday life as images formed by lenses, images formed by reflection are simpler to understand, so we discuss them first. Later we will turn to a more mathematical treatment of images made by reflection. Surprisingly, the same equations can also be applied to lenses.

1273

A Virtual Image



a) An image formed by a mirror.

We can understand a mirror image using a ray diagram. Figure a) shows several light rays, 1, that originated by diffuse reflection at the person's nose. They bounce off the mirror, producing new rays, 2. To anyone whose eye is in the right position to get one of these rays, they appear to have come from behind the mirror, 3, where they would have originated from a single point. This point is where the tip of the image-person's nose appears to be. A similar analysis applies to every other point on the person's face, so it looks as though there was an entire face behind the mirror. The customary way of describing the situation requires some explanation:

Customary description in physics: There is an image of the face behind the mirror.

Translation: The pattern of rays coming from the mirror is exactly the same as it would be if there was a face behind the mirror. Nothing is really behind the mirror.

This is referred to as a *virtual* image, because the rays do not actually cross at the point behind the mirror. They only appear to have originated there.

1075

self-check A

Imagine that the person in figure a) moves his face down quite a bit — a couple of feet in real life, or a few inches on this scale drawing. Draw a new ray diagram. Will there still be an image? If so, where is it visible from?

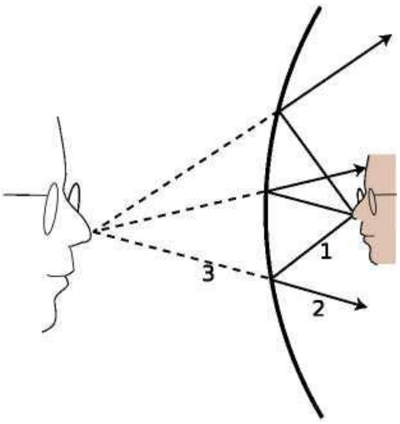
The geometry of specular reflection tells us that rays 1 and 2 are at equal angles to the normal (the imaginary perpendicular line piercing the mirror at the point of reflection). This means that ray 2's imaginary continuation, 3, forms the same angle with the mirror as ray 3. Since each ray of type 3 forms the same angles with the mirror as its partner of type 1, we see that the distance of the image from the mirror is the same as the actual face from the mirror, and lies directly
569 across from it. The image therefore appears to be the same size as the actual face.

Discussion Question

A The figure shows an object that is off to one side of a mirror. Draw a ray diagram. Is an image formed? If so, where is it, and from which directions would it be visible?

Curved Mirrors

An image in a flat mirror is a pretechnological example: even animals can look at their reflections in a calm pond. We now pass to our first nontrivial example of the manipulation of an image by technology: an image in a curved mirror. Before we dive in, let's consider why this is an important example. If it was just a question of memorizing a bunch of facts about curved mirrors, then you would rightly rebel against an effort to spoil the beauty of your liberally educated brain by force-feeding you technological trivia. The reason this is an important example is not that curved mirrors are so important in and of themselves, but that the results we derive for curved bowl-shaped mirrors turn out to be true for a large class of other optical devices, including mirrors that bulge outward rather than inward, and lenses as well.



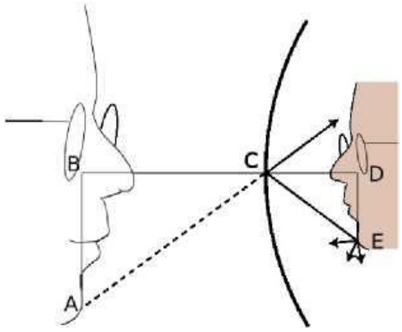
b) An image formed by a curved mirror.

A microscope or a telescope is simply a combination of lenses or mirrors or both. What you're really learning about here is the basic building block of all optical devices from movie projectors to octopus eyes.

Because the mirror in figure b) is curved, it bends the rays back closer together than a flat mirror would: we describe it as *converging.* Note that the term refers to what it does to the light rays, not to the physical shape of the mirror's surface . (The surface itself would be described as *concave.* The term is not all that hard to remember, because the hollowed-out interior of the mirror is like a cave.) It is surprising but true that all the rays like 3 really do converge on a point, forming a good image. We will not prove this fact, but it is true for any mirror whose curvature is gentle enough and that is symmetric with respect to rotation about the perpendicular line passing through its center (not asymmetric like a potato chip). The old-fashioned method of making mirrors and lenses is by grinding them in grit by hand, and this automatically tends to produce an almost perfect spherical surface.

1971 Bending a ray like 2 inward implies bending its imaginary continuation 3 outward, in the same way that raising one end of a seesaw causes the other end to go down. The image therefore forms deeper behind the mirror. This doesn't just show that there is extra distance between the image-nose and the mirror; it also implies that the image itself is bigger from front to back. It has been *magnified* in the front-to-back direction.

It is easy to prove that the same magnification also applies to the image's other dimensions. Consider a point like E in figure c). The trick is that out of all the rays diffusely reflected by E, we pick the one that happens to head for the mirror's center, C. The equal-angle property of specular reflection plus a little straightforward geometry easily leads us to the conclusion that triangles ABC and CDE are the same shape, with ABC being simply a scaled-up version of CDE. The magnification of depth equals the ratio BC/CD, and the up-down magnification is AB/DE. A repetition of the same proof shows that the magnification in the third dimension (out of the page) is also the same. This means that the image-head is simply a larger version of the real one, without any distortion. The scaling factor is called the magnification, *M*. The image in the figure is magnified by a factor *M* = 1.9.



c) The image is magnified by the same factor in depth and in its other dimensions.

Note that we did not explicitly specify whether the mirror was a sphere, a paraboloid, or some other shape. However, we assumed that a focused image would be formed, which would not necessarily be true, for instance, for a mirror that was asymmetric or very deeply curved.

1596

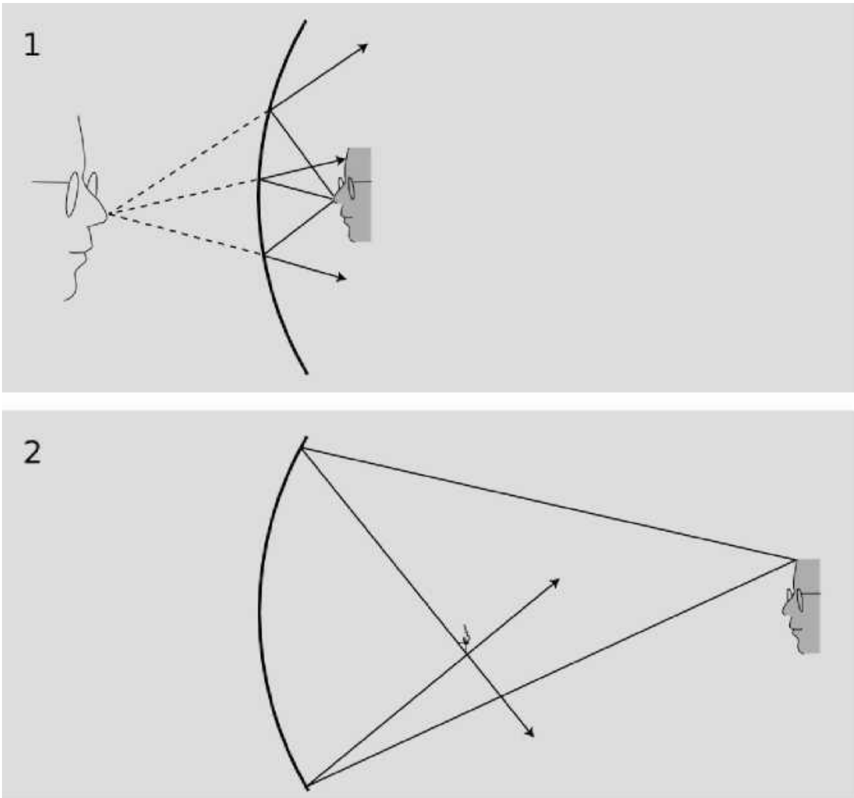
A Real Image

If we start by placing an object very close to the mirror, d)1, and then move it farther and farther away, the image at first behaves as we would expect from our everyday experience with flat mirrors, receding deeper and deeper behind the mirror. At a certain point, however, a dramatic change occurs. When the object is more than a certain distance from the mirror, d)2, the image appears upside-down and in *front* of the mirror.

Here's what's happened. The mirror bends light rays inward, but when the object is very close to it, as in d)1, the rays coming from a given point on the object are too strongly diverging (spreading) for the mirror to bring them back together.

On reflection, the rays are still diverging, just not as strongly diverging. But when the object is sufficiently far away, d)2, the mirror is only intercepting the rays that came out in a narrow cone, and it is able to bend these enough so that they will reconverge.

Note that the rays shown in the figure, which both originated at the same point on the object, reunite when they cross. The point where they cross is the image of the point on the original



d) 1. A virtual image.

2. A real image. As you'll verify in homework problem 6, the image is upside-down

object. This type of image is called a *real image*, in contradistinction to the virtual images we've studied before. The use of the word "real" is perhaps unfortunate. It sounds as though we are saying the image was an actual material object, which of course it is not.

The distinction between a real image and a virtual image is an important one, because a real image can be projected onto a screen or photographic film. If a piece of paper is inserted in figure d)2 at the location of the image, the image will be visible on the paper (provided the

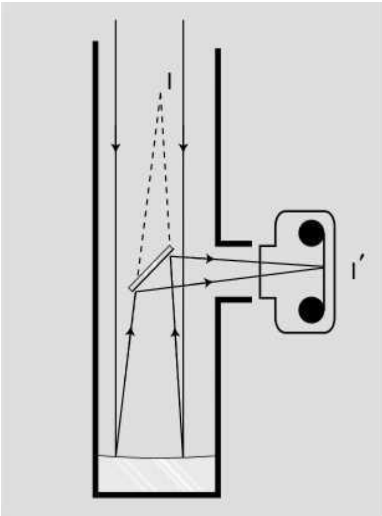
1784 object is bright and the room is dark). Your eye uses a lens to make a real image on the retina.

self-check B

Sketch another copy of the face in figure d)1, even farther from the mirror, and draw a ray diagram. What has happened to the location of the image?

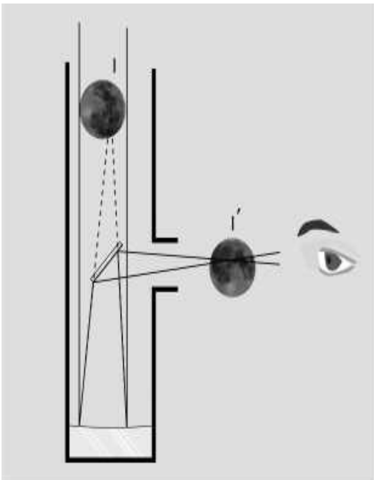
Images of Images

If you are wearing glasses right now, then the light rays from the page are being manipulated first by your glasses and then by the lens of your eye. You might think that it would be extremely difficult to analyze this, but in fact it is quite easy. In any series of optical elements (mirrors or lenses or both), each element works on the rays furnished by the previous element in exactly the same manner as if the image formed by the previous element was an actual object.



e) A Newtonian telescope being used with a camera.

Figure e) shows an example involving only mirrors. The Newtonian telescope, invented by Isaac Newton, consists of a large curved mirror, plus a second, flat mirror that brings the light out of the tube. (In very large telescopes, there may be enough room to put a camera or even a person inside the tube, in which case the second mirror is not needed.) The tube of the telescope is not vital; it is mainly a structural element, although it can also be helpful for blocking out stray light. The lens has been removed from the front of the camera body, and is not needed for this setup. Note that the two sample rays have been drawn parallel, because an astronomical telescope is used for viewing objects that are extremely far away. These two "parallel" lines actually meet at a certain point, say a crater on the moon, so they can't actually be perfectly parallel, but they are parallel for all practical purposes since we would have to follow them upward for a quarter of a million miles to get to the point where they intersect.



f) A Newtonian telescope being used for visual rather than photographic observing. In real life, an eyepiece lens is normally used for additional magnification, but this simpler setup will also work.

The large curved mirror by itself would form an image I, but the small flat mirror creates an image of the image, I'. The relationship between I and I' is exactly the same as it would be if I was an actual object rather than an image: I and I' are at equal distances from the plane of the mirror, and the line between
1886 them is perpendicular to the plane of the mirror.

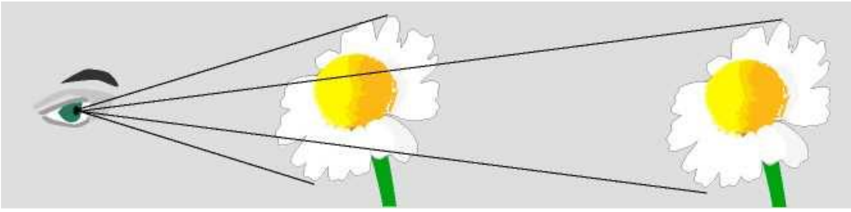
One surprising wrinkle is that whereas a flat mirror used by itself forms a virtual image of an object that is real, here the mirror is forming a real image of virtual image I. This shows how pointless it would be to try to memorize lists of facts about what kinds of images are formed by various optical elements under various circumstances. You are better off simply drawing a ray diagram.

Although the main point here was to give an example of an image of an image, figure f) shows an interesting case where we need to make the distinction between *magnification* and *angular magnification.* If you are looking at the moon through this telescope, then the images I and I' are much *smaller* than the actual moon. Otherwise, for example, image I would not fit inside the telescope! However, these images are very close to your eye compared to the actual moon. The small size of the image has been more than

compensated for by the shorter distance. The important thing here is the amount of *angle* within your field of view that the image covers, and it is this angle that has been increased. The factor
1163 by which it is increased is called the *angular magnification*, M_a.

Summary

Selected Vocabulary



g) The angular size of the flower depends on its distance from the eye.

Real image	a place where an object appears to be, because the rays diffusely reflected from any given point on the object have been bent so that they come back together and then spread out again from the new point
Virtual image	like a real image, but the rays don't actually cross again; they only appear to have come from the point on the image
Converging	describes an optical device that brings light rays closer to the optical axis
Diverging	bends light rays farther from the optical axis
Magnification	the factor by which an image's linear size is increased (or
Angular magnification	the factor by which an image's apparent angular size is increased (or decreased)
Concave	describes a surface that is hollowed out like a cave
Convex	describes a surface that bulges outward

Notation

M	the magnification of an image
M_a	the angular magnification of an image

A large class of optical devices, including lenses and flat and curved mirrors, operates by bending light rays to form an image. A real image is one for which the rays actually cross at each point of the image. A virtual image, such as the one formed behind a flat mirror, is one for which the rays only appear to have crossed at a point on the image. A real image can be projected onto a screen; a virtual one cannot.

Mirrors and lenses will generally make an image that is either smaller than or larger than the original object. The scaling factor is called the magnification. In many situations, the angular
679 magnification is more important than the actual magnification.

Текст 5

Задание

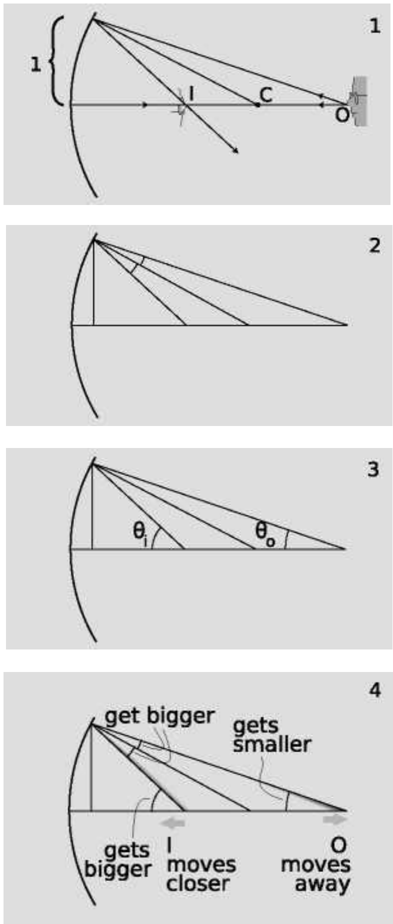
Найдите в Тексте 5 ответы на следующие вопросы:

1. What is the sole mathematical fact we possess concerning specular reflection?
2. What is the dioptric strength of a mirror?
3. How to find where a lightbulb should be placed in a searchlight?
4. What are the two approaches of measuring the focal length?

A Real Image Formed by a Converging Mirror

Location of the image

We will now derive the equation for the location of a real image formed by a converging mirror. We assume for simplicity that the mirror is spherical, but actually this isn't a restrictive assumption, because any shallow, symmetric curve can be approximated by a sphere. The shape of the mirror can be specified by giving the location of its center, C. A deeply curved mirror is a sphere with a small radius, so C is close to it, while a weakly curved mirror has C farther away. Given the point O where the object is, we wish to find the point I where the image will be formed.



h) The relationship between the object's and the image's positions can be expressed in terms of the angles θ_o and θ_i

To locate an image, we need to track a minimum of two rays coming from the same point. Since we have proved in the previous chapter that this type of image is not distorted, we can use an on-axis point, O, on the object, as in figure h)1. The results we derive will also hold for off-axis points, since otherwise the image would have to be distorted, which we know is not true. We let one of the rays be the one that is emitted along the axis; this ray is especially easy to trace, because it bounces straight back along the axis again.

As our second ray, we choose one that strikes the mirror at a distance of 1 from the axis. "One what?" asks the astute reader. The answer is that it doesn't really matter. When a mirror has shallow curvature, all the reflected rays hit the same point, so 1 could be expressed in any units you like. It could, for instance, be 1 cm, unless your mirror is smaller than 1 cm!

The only way to find out anything mathematical about the rays is to use the sole mathematical fact we possess concerning specular reflection: the incident and reflected rays form equal angles with respect to the normal, which is shown as a dashed line. Therefore the two angles shown in figure h)2 are the same, and skipping some straightforward geometry, this leads to the visually reasonable result that the two angles in figure h)3 are related as follows:

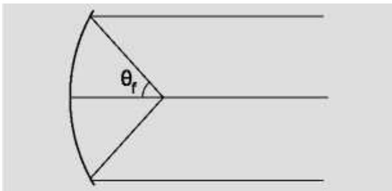
2006

$$\theta_i + \theta_o = constant$$

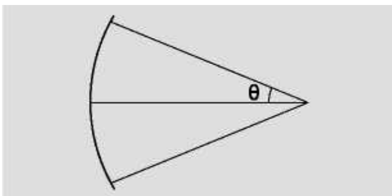
(Note that θ_i and θ_o, which are measured from the image and the object) For example, move O farther from the mirror. The top angle in figure h)2 is increased, so the bottom angle must increase by the same amount, causing the image point, I, to move closer to the mirror. In terms of the angles shown in figure h)3, the more distant object has resulted in a smaller angle θ_o, while the closer image corresponds to a larger θ_i; one angle increases by the same amount that the other decreases, so their sum remains constant. These changes are summarized in figure h)4.

The sum $\theta_i + \theta_o$ is a constant. What does this constant represent? Geometrically, we interpret it as double the angle made by the dashed radius line. Optically, it is a measure of the strength of the mirror, i.e., how strongly the mirror focuses light, and so we call it the focal angle, θ_f,

$$\theta_i + \theta_o = \theta_f \quad .$$



i) The geometrical interpretation of the focal angle.



j) Example 1, an alternative test for finding the focal angle. The mirror is the same as in figure b.

Suppose, for example, that we wish to use a quick and dirty optical test to determine how strong a particular mirror is. We can lay it on the floor as shown in figure c, and use it to make an image of a lamp mounted on the ceiling overhead, which we assume is very far away compared to the radius of curvature of the mirror, so that the mirror intercepts only a very narrow cone of rays from the lamp. This cone is so narrow that its rays are nearly parallel, and θ_o is nearly zero. The real image can be observed on a piece of paper. By moving the paper nearer and farther, we can bring the image into focus, at which point we know the paper is located at the image point. Since $\theta_o \approx 0$, we have $\theta_i \approx \theta_f$, and we can then determine this mirror's focal angle either by measuring θ_i directly with a protractor, or indirectly via trigonometry. A strong mirror will bring the rays together to form an image close to the mirror, and these rays will form a blunt-angled cone with a large θ_i

1860 and θ_f.

An alternative optical test *example 1*

► Figure j) shows an alternative optical test. Rather than placing the object at infinity as in figure i), we adjust it so that the image is right on top of the object. Points O and I coincide, and the rays are reflected right back on top of themselves. If we measure the angle 0 shown in figure j), how can we find the focal angle?

► The object and image angles are the same; the angle labeled 0 in the figure equals both of them. We therefore have $\theta_i + \theta_o = \theta = \theta_f$. Comparing figures i) and j), it is indeed plausible that the angles are related by a factor of two.

At this point, we could consider our work to be done. Typically, we know the strength of the mirror, and we want to find the image location for a given object location. Given the mirror's focal angle and the object location, we can determine θ_o by trigonometry, subtract to find $\theta_i = \theta_f - \theta_o$, and then do more trig to find the image location.

There is, however, a shortcut that can save us from doing so much work. Figure h)3 shows two right triangles whose legs of length 1 coincide and whose acute angles are θ_o and θ_i. These can be related by trigonometry to the object and image distances shown in figure k):

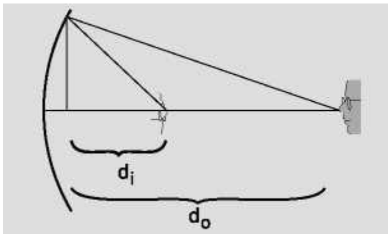
$$\tan\theta_o = 1/d_o \qquad \tan\theta_i = 1/d_i \quad ,$$

Up to now, we've been assuming small angles. For small angles, we can use the small-angle approximation $\tan x \approx x$ (for x in radians), giving simply

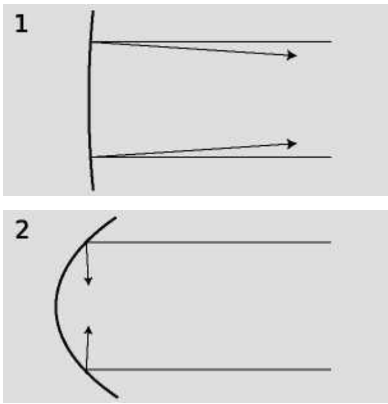
$$\theta_o = 1/d_o \qquad \theta_i = 1/d_i \quad .$$

We likewise define a distance called the focal length, f according to $\theta_f = 1/f$. In figure i), f is the distance from the mirror to the place where the rays cross.

We can now re-express the equation relating the object and image positions as



k) The object and image distances



l) Mirror 1 is weaker than mirror 2. It has a shallower curvature, a longer focal length, and a smaller focal angle. It reflects rays at angles not much different than those that would be produced with a flat mirror.

$$1/f = 1/d_i + 1/d_o$$

Figure l) summarizes the interpretation of the focal length and focal angle.[1]

Which form is better, $\theta_f = \theta_i + \theta_o$ or $1/f = 1/d_i + 1/d_o$? The angular form has in its favor its simplicity and its straightforward visual interpretation, but there are two reasons why we might prefer the second version. First, the numerical values of the angles depend on what we mean by "one unit" for the distance shown as 1 in figure h)1. Second, it is usually easier to measure distances rather than angles, so the distance form is more convenient for number crunching. Neither form is superior overall, and we will often need to use both to solve any given problem.

1711

A searchlight *Example 2*

Suppose we need to create a parallel beam of light, as in a searchlight. Where should we place the lightbulb? A parallel beam has zero angle between its rays, so $\theta_j = 0$. To place the lightbulb correctly, however, we need to know a distance, not an angle: the distance d_o between the bulb and the mirror. The problem involves a mixture of distances and angles, so we need to get everything in terms of one or the other in order to solve it. Since the goal is to find a distance, let's figure out the image distance corresponding to the given angle $\theta_j = 0$. These are related by $d_j = 1/\theta_j$, so we have $d_j = \infty$. (Yes, dividing by zero gives infinity. Don't be afraid of infinity. Infinity is a useful problem-solving device.) Solving the distance equation for d_o, we have

$$\begin{aligned} d_o &= (1/f - 1/d_j) - 1 \\ &= (1/f - 0) - 1 \\ &= (1/f) - 1 \\ &= f \end{aligned}$$

The bulb has to be placed at a distance from the mirror equal to its focal point.

Diopters *Example 3*

An equation like $d_j = 1/\theta_i$ really doesn't make sense in terms of units. Angles are unitless, since radians aren't really units, so the right-hand side is unitless. We can't have a left-hand side with units of distance if the right-hand side of the same equation is unitless. This is an artifact of my cavalier statement that the conical bundles of rays spread out to a distance of 1 from the axis where they strike the mirror, without specifying the units used to measure this 1. In real life, optometrists define the thing we're calling $\theta_i = 1/d_j$ as the "dioptric strength" of a lens or mirror,

[1] There is a standard piece of terminology which is that the "focal point" is the point lying on the optical axis at a distance from the mirror equal to the focal length. This term isn't particularly helpful, because it names a location where nothing normally happens. In particular, it is not normally the place where the rays come to focus! – that would be the image point. In other words, we don't normally have $d_i = f$, unless perhaps $d_o = \infty$. A recent online discussion among some physics teachers showed that many disliked the terminology, felt it was misleading, or didn't know it and would have misinterpreted it if they had come across it. That is, it appears to be what grammarians call a "skunked term" – a word that bothers half the population when it's used incorrectly, and the other half when it's used correctly.

and measure it in units of inverse meters (m^{-1}), also known as diopters (1 D=1 m^{-1}).

Magnification

We have already discussed in the previous chapter how to find the magnification of a virtual image made by a curved mirror. The result is the same for a real image, and we omit the proof, which is very similar. In our new notation, the result is M = d_i / d_o.

Other cases with Curved Mirrors

The equation d_i = can easily produce a negative result, but we have been thinking of d_i as a distance, and distances can't be negative. A similar problem occurs with $\theta_i = \theta_f - \theta_o$ for $\theta_o > \theta_f$. What's going on here?

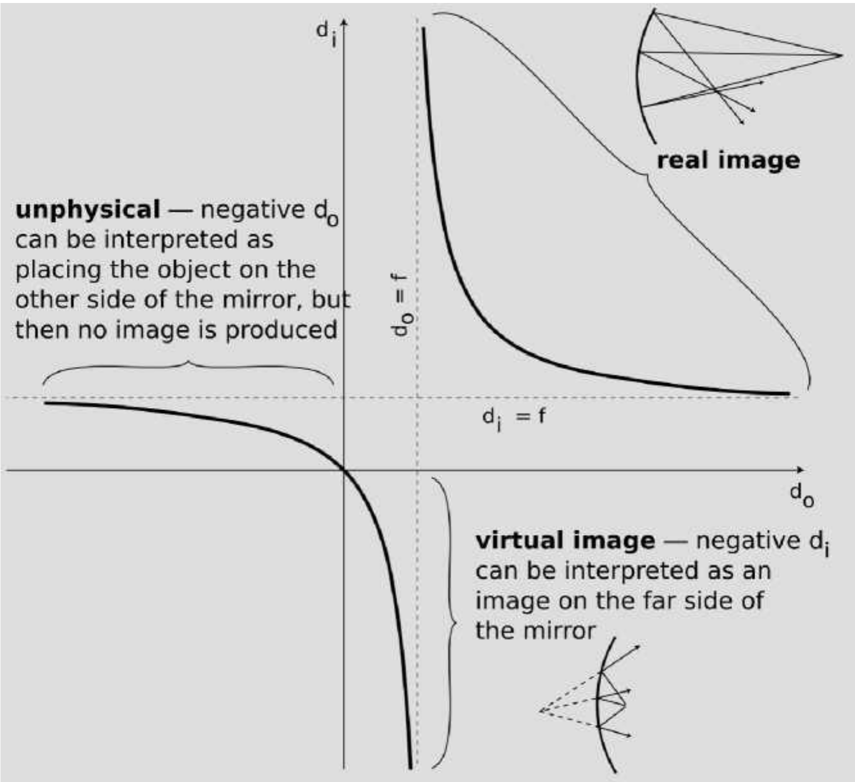
The interpretation of the angular equation is straightforward. As we bring the object closer and closer to the image, θ_o gets bigger and bigger, and eventually we reach a point where $\theta_o = \theta_f$ and $\theta_i = 0$. This large object angle represents a bundle of rays forming a cone that is very broad, so broad that the mirror can no longer bend them back so that they re-converge on the axis. The image angle $\theta_i = 0$ represents an outgoing bundle of rays that are parallel. The outgoing rays never cross, so this is not a real image, unless we want to be charitable and say that the rays cross at infinity. If we go on bringing the object even closer, we get a virtual image.

To analyze the distance equation, let's look at a graph of d_i as a function of d_o. The branch on the upper right corresponds to the case of a real image. Strictly speaking, this is the only part of the graph that we've proven corresponds to reality, since we never did any geometry for other cases, such as virtual images. As discussed in the previous section, making d_o bigger causes d_i to become smaller, and vice-versa.

Letting d_o be less than f is equivalent to $\theta_o > \theta_f$: a virtual image is produced on the far side of the mirror. This is the first example of Wigner's "unreasonable effectiveness of mathematics" that we have encountered in optics. Even though our proof depended on the assumption that the image was real, the equation we derived turns out to be applicable to virtual images, provided that we either interpret the positive and negative signs in a certain way, or else modify the
2132 equation to have different positive and negative signs.

self-check A

Interpret the three places where, in physically realistic parts of the graph, the graph approaches one of the dashed lines. [This will come more naturally if you have learned the concept of limits in a math class.]



m) A graph of the image distance *d;* as a function of the object distance d_o.

A flat mirror *Example 4*

We can even apply the equation to a flat mirror. As a sphere gets bigger and bigger, its surface is more and more gently curved. The planet Earth is so large, for example, that we cannot even perceive the curvature of its surface. To represent a flat mirror, we let the mirror's radius of curvature, and its focal length, become infinite. Dividing by infinity gives zero, so we have

$$1/d_o = - 1/d_j$$

or

$$d_o = - d_j$$

If we interpret the minus sign as indicating a virtual image on the far side of the mirror from the object, this makes sense.

It turns out that for any of the six possible combinations of real or virtual images formed by converging or diverging lenses or mirrors, we can apply equations of the form

$$\theta_f = \theta_i + \theta_o$$

and

$$1/f = 1/d_i + 1/d_o$$

with only a modification of plus or minus signs. There are two possible approaches here. The approach we have been using so far is the more popular approach in American books: leave the equation the same, but attach interpretations to the resulting negative or positive values of the variables. The trouble with this approach is that one is then forced to memorize tables of sign conventions, e.g. that the value of d_i should be negative when the image is a virtual image formed by a converging mirror. Positive and negative signs also have to be memorized for focal lengths. Ugh! It's highly unlikely that any student has ever retained these lengthy tables in his or her mind for more than five minutes after handing in the final exam in a physics course. Of course one can always look such things up when they are needed, but the effect is to turn the whole thing into an exercise in blindly plugging numbers into formulas.

As you have gathered by now, there is another method, which is better, and which will be used throughout the rest of this book. In this method, all distances and angles are *positive by definition,* and we put in positive and negative signs in the *equations* depending on the situation. Rather than memorizing these signs, we start with the generic equations

$$\theta_f = \pm\theta_i \pm \theta_o$$

$$1/f = \pm 1/d_i \pm 1/d_o\ ,$$

and then determine the signs by a two-step method that depends on ray diagrams. There are really only two signs to determine, not four; the signs in the two equations match up in the way you'd expect. The method is as follows:

1. Use ray diagrams to decide whether θ_o and θ_i vary in the same way or in opposite ways. (In other words, decide whether making θ_o greater results in a greater value of θ_i or a smaller one.) Based on this, decide whether the two signs in the angle equation are the same or opposite. If the signs are opposite, go on to step 2 to determine which is positive and which is negative.

2. If the signs are opposite, we need to decide which is the positive one and which is the negative. Since the focal angle is never negative, the smaller angle must be the one with a minus sign.

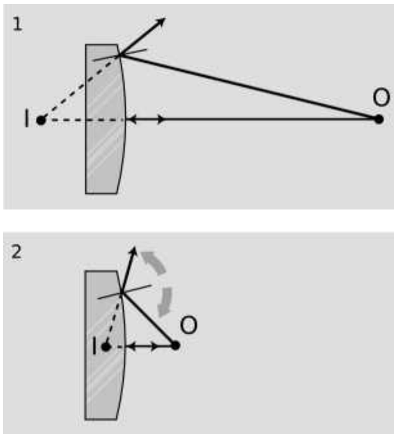
In step 1, many students have trouble drawing the ray diagram correctly. For simplicity, you should always do your diagram for a point on the object that is on the axis of the mirror, and let one of your rays be the one that is emitted along the axis and reflect straight back on itself, as in the figures above. As shown in figure h)4, there are four angles involved: two at the mirror, one at the object (θ_o), and one at the image (θ_i). Make sure to draw in the normal to the mirror so that you can see the two angles at the mirror. These two angles are equal, so as you change the object position, they fan out or fan in, like opening or closing a book. Once you've drawn this effect, you should easily be able to tell whether θ_o and θ_i change in the same way or in opposite ways.

Although focal lengths are always positive in the method used in this book, you should be aware that diverging mirrors and lenses are assigned negative focal lengths in the other method, so if
3346 you see a lens labeled f = -30 cm, you'll know what it means.

An anti-shoplifting mirror *Example 5*

► Convenience stores often install a diverging mirror so that the clerk has a view of the whole store and can catch shoplifters. Use a ray diagram to show that the image is reduced, bringing more into the clerk's field of view. If the focal length of the mirror is 3.0 m, and the mirror is 7.0 m from the farthest wall, how deep is the image of the store?

► As shown in ray diagram n)1, d_j is less than d_o. The magnification, $M = d_j/d_o$, will be less than one, i.e., the image is actually reduced rather than magnified.



n) Example 5

Apply the method outlined above for determining the plus and minus signs. Step 1: The object is the point on the opposite wall. As an experiment, n)2, move the object closer. I did these drawings using illustration software, but if you were doing them by hand, you'd want to make the scale much larger for greater accuracy. Also, although I split figure n) into two separate drawings in order to make them easier to understand, you're less likely to make a mistake if you do them on top of each other.

The two angles at the mirror fan out from the normal. Increasing θ_o has clearly made θ_j larger as well. (All four angles got bigger.) There must be a cancellation of the effects of changing the two terms on the right in the same way, and the only way to get such a cancellation is if the two terms in the angle equation have opposite signs:

$$\theta_f = +\theta_j - 0_o$$

or

$$\theta_f = - \theta_j + \theta_o$$

Step 2: Now which is the positive term and which is negative? Since the image angle is bigger than the object angle, the angle equation must be

$$\theta_f = \theta_j - \theta_o$$

in order to give a positive result for the focal angle. The signs of the distance equation behave the same way:

$$1/f = 1/d_j - 1/d_{o.}$$

Solving for d_j, we find

$$d_j = (1/f + 1/d_o)^{-1}$$

$$= 2.1\text{m.}$$

The image of the store is reduced by a factor of 2.1 /7.0 = 0.3, i.e., it is smaller by 70%.

A shortcut for real images *Example 6*

In the case of a real image, there is a shortcut for step 1, the determination of the signs. In a real image, the rays cross at both the object and the image. We can therefore time-reverse the ray diagram, so that all the rays are coming from the image and re-converging at the object. Object and image swap roles. Due to this time-reversal symmetry, the object and image cannot be treated differently in any of the equations, and they must therefore have the same signs. They are both positive, since they must add up to a positive result.

Англо-русский словарь

A

A bit .... немного, малое количество;
Absorb .... поглощать;
Accept.. принимать;
Actual............... действительный, фактический;
Advantage .... преимущество;
Alert .... бдительный;
Alignment.................................. выравнивание;
Amaze .... поражать, изумлять;
Antic............... комичный, нелепый, абсурдный;
Artificial .... искусственный;
Associate .... связывать, ассоциировать;
Assume.............................. полагать, допускать;

B

Backtrack........................... отходить, отступать;
Ballpark.............приблизительный, примерный;
Refer to as .... называть;
Beam ....пучок;
Bend ....отклоняться, изгибать;
Bizarre ....странный, причудливый, эксцентричный;
Block.................. преграждать, препятствовать;
Bounce ....отскакивать;
Bowl-shaped..................имеющий форму чаши;
Brag ....хвалиться;
Brain .... мозг;
Brute force ....грубая сила;
Bulb ....колба лампы, лампа накаливания;
Bulge ..вздуваться, выпячиваться, выдаваться;
Bump ....ударяться;
Bunch .... букет, группа чего-либо;

C

Calm ....спокойный;
Candle ....свеча, кандела (ед. измерения)
Cannonball .... пушечное ядро;
Carefully .... тщательно, внимательно;
Casually................непреднамеренно; случайно;
Cause ....причина; причинять, вызывать;
Cause and effect .... причинно-следственный;
Caution .... предупреждение; предостерегать;
Cave ....пещера, углубление, впадина;
Charge.. заряд;
Claim .... заявлять, утверждать;
Clap ....хлопать в ладоши;
Clutter up.............. перегружать, загромождать;
Collide ....сталкиваться;
Collision...................................... столкновение;
Come up (with) ....предлагать (решение);
Compare...сравнивать;
Concave .... вогнутый
Conceivable ....мыслимый, возможный;
Conceptual ....понятийный;
Conceptualize ....осмысливать;
Conclusion..........................вывод, заключение;
Conduction .... проводимость
Confine .... ограничивать
Confuse......................................смущать (-ся)
Contribute.........способствовать, вносить вклад;
Convenience ....удобство;
Convention .... соглашение договоренность;
Converging ....собирающий, сводящий;
Convert ....обращать, превращать, преобразовывать;
Convert............ преобразовывать; превращать,
Convince .... убеждать;
Countertop....................... рабочая поверхность;
Crater .... кратер;
Crumple... мять;
Cumbersome................... тяжелый, громоздкий;
Curvature... кривизна;
Curved mirror .... кривое зеркало;
Customary .... обычный;

D

Deflect .... отклонять;
Delay ....промедление, задержка;
Despite .... несмотря на;
Destination .... цель, назначение;

Detectable .... поддающийся обнаружению;
Diffuse .... рассеянный, диффузный;
Dimension.......................... размер, измерение;
Discovery.. открытие;
Dismiss .... отвергать;
Display.............. демонстрировать, показывать;
Distinction .... различие;
Distortion .... искажение;
Dive in.............................. погружаться, нырять;
Diverge .... расходиться;
Draw (near)........ приближаться, пододвигаться;
Due to .... из-за;

E

Emission .... испускание излучение;
Emit .... испускать, излучать;
En route .... в пути, по дороге;
Encounter ....встречаться, наталкиваться;
Environment .... окружающая среда;
Evidence .... доказательство;
Evident..............очевидный, явный, наглядный;
Example.. пример;
Exert ....прилагать (усилия);
Expand ....расширять;
Explicitly........................ явно; недвусмысленно;
Exploit ....использовать;
Expose..подвергать чему-либо, экспонировать;

F

Fairly .... достаточно, довольно;
Familiarity .... знакомство, осведомленность;
Fan out .... разворачивать веером;
Fascinate ....увлекать, вызывать восторг;
Fastidiously............. разборчиво, привередливо;
Filament............................. нить (накаливания);
Filament lamp.....................лампа накаливания;
Finite .... ограниченный, имеющий предел;
Flame.................................. пламя, яркий свет;
Flatten.....................выравнивать, сплющивать;
Fluorescent...................................светящийся;
Foil.......................фольга; зеркальная наводка;

Friction... трение;
Furnish ...снабжать, обеспечивать, доставлять;

G

Generic........... родовой, характерный для рода;
Glow ....светиться, сверкать;
Gradual.. постепенный;
Grain..зерно;
Grind...шлифовать;
Grit...песок;
Guide .... руководство;

H

Harm... вред, ущерб;
Heat... тепло;
Hollow................................ пустой, пустотелый;
Horrifically........................ ужасно, чрезвычайно;
Hose .... шланг (для полива);

I

Immune .... невосприимчивый;
Imply..................подразумевать, предполагать;
Imprecise.............. неточный, неопределенный;
Impressive .... впечатляющий;
In contradiction to .... в отличие от;
Incandescent.......раскаленный, светящийся от нагрева;
Incident ray................................падающий луч;
Incompatible .... несовместимый;
Infinite .... бесконечный, беспредельный;
Infinitesimal .....очень малый, не поддающийся измерению;
Influential ....влиятельный;
Insect... насекомое;
Inset........... вставлять, вкладывать, помещать;
Instantaneous....... мгновенный, моментальный;
Instead of...............................вместо чего-либо;
Intelligent ....разумный, умный;
Interact .... взаимодействовать;
Intercept ....перехватывать;

Interface............................поверхность раздела;
Intervene.................происходить; вмешиваться;
Inward...внутрь;

J

Judicious ....разумный, рассудительный; целесообразный, продуманный;

L

Lag..отставание;
Law ....закон;
Leaf... лист;
Liberally ....щедро, в изобилии;
Loudness .... громкость;
Luminous ....светящийся;

M

Magnification .... увеличение;
Magnify...увеличивать;
Magnifying glass........... увеличительное стекло;
Magnifying power ....кратность увеличения;
Manifestation ....проявление;
Matter ....вещество;
Mean..означать;
Measure.. измерять;
Medium (pl. media).......................среда (среды);
Mostly .... главным образом;

N

Net .... общий, результативный, суммарный;
Neurological............................ неврологический;
Nicety................................точность, изящество;
Nonsensical.............бессмысленный, нелепый;

O

Obey ....подчиняться;
Obscure ....делать неясным, запутывать;
Occur ....случаться, происходить;
Octopus .... восьминогое животное;
Offset..................возмещать, компенсировать; выравнивать;
Omit............................ опускать, пренебрегать;
Only .... только;
Opaque......................................непрозрачный;
Originate..................давать начало, создавать, происходить;
Oscillation......................... вибрация, колебание;
Outward .... наружу;

P

Palm .... ладонь;
Particle ....частица;
Pendulum .... маятник;
Perceive……..... ....ощущать, чувствовать, воспринимать;
Physiology......................................физиология;
Pierce ....проникать, проходить сквозь;
Pointless............ бессмысленный, бесцельный.
Pond .... пруд;
Power .... энергия, мощность;
Precedence .... приоритет, преимущество;
Predate.......происходить до какого-либо числа.
Predict ....предсказывать;
Pressure ....давление;
Presumably ......предположительно, возможно, вероятно;
Pre-technological .... до технологической революции;
Proof............. подтверждение, доказательство;
Propagation ....распространение;

R

Random......................................произвольный;
Ratio ....отношение;
Rebel ....протестовать;
Recede .... отступать, удаляться;
Recognize .... узнавать, опознавать;
Reflect ....отражать;
Regardless .... независимо, безотносительно, несмотря на;

Relationship......................... взаимоотношение;
Relevant .... уместный, важный, насущный;
Reliability .... надежность;
Rely (on) .... полагаться (на);
Repetition .... повторение;
Rephrase ....перефразировать;
Result (in) .... выражаться (в);
Retina .... сетчатка;
Rock ....камень;
Roll .... вал, ролик;
Rote .... механическое запоминание;
Rough .... грубый;

S

Scale...................................... масштабировать;
Seem .... казаться;
Seesaw... качели;
Set .... комплект, набор, ряд;
Setup .... ставить, устанавливать;
Shade .... тень;
Shortcut .... кратчайший путь;
Silver...серебро;
Similarity ....сходство, подобие;
Sketch...................... схематически изображать;
Slide.....................плавно двигаться, скользить;
Smart.… ....толковый, сообразительный, способный, умный, ловкий;
Smooth .... гладкий;
Sophisticated ....сложный, продуманный;
Source ....источник;
Specify.................. определять, устанавливать;
Specular .... зеркальный, отражающий;
Specular reflection......... зеркальное отражение;
Spoil..портить;
Spontaneous ... стихийный, самопроизвольный;
Spooky.............................. зловещий, странный;
Stove .... печь;
Straightforward ...... прямой, непосредственный;
Strain .... напрягать;
Stray radiation ....рассеянное излучение;
Stuff .... материал, вещество;
Substance .... вещество; (физ.) тело;
Subtle .... тонкий, едва различимый;
Succeed (in) .... добиться, суметь сделать;
Suck up ....поглощать, впитывать;
Sufficiently ....достаточно;
Summary. резюме, сводка, краткое изложение

T

The only.......................................единственный;
Thing .... вещь; предмет; явление; нечто;
Timbre .... тембр;
Time-reversal .... обратимость во времени;
Title.................................... заглавие, название;
Trace .... прослеживать;
Triangle ....треугольник;
Trick... прием, способ;
Trivia.......................................мелочи, пустяки;
Truth .... правда;

U

Ultimate .... окончательный;
Uncover ....раскрывать, снимать;
Under-utilize .... недоиспользовать;
Uneasy .... неудобный, нелегкий;
Unite .... объединять;
Unwieldy.. громоздкий;
Upholstery ....обивка;
Upside-down ....вверх ногами;

V

Variety .... разнообразие, многообразие;
Verify .... подтверждать, проверять, поверять;
Virtual image ....мнимое изображение;
Vision .... зрение, зрительное восприятие;
Vital ....насущный, жизненно необходимый;

W

Waist .... терять;
Wand .... тонкая палочка;
Wave .... волна;

Wieldy.............легко управляемый, послушный;
Wrinkle..............................морщина, недостаток;

Таблица неправильных глаголов

TABLE OF IRREGULAR VERBS			
Infinitive	***Past Tense***	***Participle II***	***Russian equivalents***
abide	abode, abided	abode, abided	пребывать; держаться
arise	arose	arisen	подняться; возникнуть
awake	awoke	awaked	будить; проснуться
be	was, were	been	быть
bear	bore	born	нести; родить
beat	beat	beaten	бить
become	became	become	стать, сделаться
befall	befell	befallen	случиться
begin	began	begun	начать
bend	bent	bent	согнуть (ся)
beseech	besought	besought	умолять, упрашивать
bid	bad(e), bid	bid(den)	велеть; просить
bind	bound	bound	связать
bite	bit	bit(ten)	кусать
bleed	bled	bled	кровоточить
blow	blew	blown	дуть
break	broke	broken	(с)ломать
breed	bred	bred	выращивать
bring	brought	brought	принести
build	built	built	строить
burn	burnt	burnt	жечь; гореть
burst	burst	burst	разразиться
buy	bought	bought	взорваться, купить
cast	cast	cast	кидать; лить *(металл)*
catch	caught	caught	ловить, поймать
choose	chose	chosen	выбрать
cleave	clove, cleft	cloven, cleft	рассечь
cling	clung	clung	цепляться; льнуть
come	came	come	прийти

Infinitive	*Past Tense*	*Participle II*	*Russian equivalents*
cost	cost	cost	стоить
creep	crept	crept	ползти
cut	cut	cut	резать
dare	durst, dared	dared	сметь
deal	dealt	dealt	иметь дело
dig	dug	dug	копать
do	did	done	делать
draw	drew	drawn	тащить; рисовать
dream	dreamt, dreamed	dreamt, dreamed	грезить, мечтать
drink	drank	drunk	пить, выпить
drive	drove	driven	гнать; ехать
dwell	dwelt	dwelt	обитать; задерживаться
eat	ate	eaten	кушать, есть
fall	fell	fallen	падать
feed	fed	fed	кормить
feel	felt	felt	чувствовать
fight	fought	fought	сражаться
find	found	found	находить
flee	fled	fled	бежать, спасаться
fling	flung	flung	бросить
fly	flew	flown	летать
forbid	forbade	forbidden	запретить
forget	forgot	forgotten	забыть
forgive	forgave	forgiven	Простить
freeze	froze	frozen	замерзнуть; замораживать
get	got	got	получить
gild	gilt, gilded	gilt, gilded	позолотить
give	gave	given	дать
go	went	gone	идти, уходить
grind	ground	ground	точить; молоть
grow	grew	grown	расти
hang	hung, hanged	hung, hanged	висеть; повесить

Infinitive	*Past Tense*	*Participle II*	*Russian equivalents*
hear	heard	heard	слышать
have	had	had	иметь
hew	hewed	hewed, hewn	рубить, тесать
hide	hid	hidden	прятать(-ся)
hit	hit	hit	ударить; попасть
hold	held	held	держать
hurt	hurt	hurt	причинить боль
keep	kept	kept	Хранить
kneel	knelt	knelt	становиться на колени
knit	knit	knit(ted)	вязать
know	knew	known	знать
lay	laid	laid	класть, положить
lead	led	led	вести
lean	leant, leaned	leant, leaned	опереться, прислониться
leap	leapt, leaped	leapt, leaped	прыгать
learn	learnt, learned	learnt, learned	учить
leave	left	left	оставить
lend	lent	lent	одолжить
let	let	let	пустить; дать
lie	lay	lain	лежать
light	lit	lit	осветить
lose	lost	lost	терять
make	made	made	делать
mean	meant	meant	подразумевать
meet	met	met	встретить
mishear	misheard	misheard	ослышаться
mislead	misled	misled	ввести в заблуждение
mistake	mistook	mistaken	неправильно понимать
mow	mowed	mown	косить
pay	paid	paid	платить
put	put	put	класть
read	read	read	читать
rebuild	rebuilt	rebuilt	перестроить

Infinitive	*Past Tense*	*Participle II*	*Russian equivalents*
ride	rode	ridden	ездить верхом
ring	rang	rung	звонить
rise	rose	risen	подняться
run	ran	run	бежать, течь
saw	sawed	sawn, sawed	пилить
say	said	said	говорить, сказать
see	saw	seen	видеть
seek	sought	sought	искать
sell	sold	sold	продавать
send	sent	sent	послать
set	set	set	устанавливать
sew	sewed	sewed, sewn	шить
shake	shook	shaken	трясти
shave	shaved	shaved, shaven	брить(ся)
shear	sheared	shorn	стричь
shed	shed	shed	проливать
shine	shone	shone	светить, сиять
shoe	shod	shod	обучать; подковывать
shoot	shot	shot	стрелять; давать побеги
show	showed	shown	показывать;
shrink	shrank	shrunk	сокращаться, сжиматься
shut	shut	shut	закрывать
sing	sang	sung	петь
sink	sank	sunk	опускаться, погружаться
sit	sat	sat	сидеть
sleep	slept	slept	спать
slide	slid	slid	скользить
smelt	smelt	smelt	пахнуть: нюхать
sow	sowed	sowed, sown	(по)сеять
speak	spoke	spoken	говорить
speed	sped	sped	ускорять; спешить
spell	spelt, spelled	spelt, spelled	писать / читать по буквам

Infinitive	*Past Tense*	*Participle II*	*Russian equivalents*
spend	spent	spent	тратить
spill	spilt, spilled	spilt, spilled	пролить
spin	spun, span	spun	прясть
spit	spat	spat	плевать
split	split	split	расщепить(ся)
spoil	spoilt, spoiled	spoilt, spoiled	портить
spread	spread	spread	распространить(ся)
spring	sprang	sprung	вскочить; возникнуть
stand	stood	stood	стоять
steal	stole	stolen	украсть
stick	stuck	stuck	уколоть; приклеить
sting	stung	stung	ужалить
stink	stank, stunk	stunk	вонять
strew	strewed	strewn, strewed	усеять, устлать
stride	strode	stridden	шагать
strike	struck	struck	ударить, бить; бастовать
string	strung	strung	нанизать; натянуть
strive	strove	striven	стараться
swear	swore	sworn	(по)клясться, присягнуть
sweep	swept	swept	мести; промчаться
swell	swelled	swollen	вздуться
swim	swam	swum	плыть
swing	swung	swung	качаться
take	took	taken	взять, брать
teach	taught	taught	учить
tear	tore	torn	рвать
tell	told	told	рассказать, сказать
think	thought	thought	думать
throw	threw	thrown	бросить
thrust	thrust	thrust	толкнуть; сунуть
tread	trod	trodden	ступать
unbend	unbent	unbent	разогнуть(ся)
understand	understood	understood	понимать

Infinitive	*Past Tense*	*Participle II*	*Russian equivalents*
undertake	undertook	undertaken	предпринять
upset	upset	upset	опрокинуть(ся)
wake	woke, waked	woken, waked	просыпаться; будить
wear	wore	worn	носить (одежду)
weave	wove	woven	ткать
weep	wept	wept	плакать
win	won	won	выигрывать
wind	wound	wound	заводить (механизм)
withdraw	withdrew	withdrawn	взять назад; отозвать
wring	wrung	wrung	скрутить; сжать
write	wrote	written	писать