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Introduction to Physics & Nanotechnology: part 3

Учебное пособие

Саратов

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INTRODUCTION TO PHYSICS & NANOTECHNOLOGY: part 3: Учебное пособие по физике и нанотехнологиям для студентов неязыкового вуза /Сост. А.И. Матяшевская, Е.В. Тиден. — Саратов, 2016. — 65 с.

Предлагаемое учебное пособие представляет собой тексты по данной специальности с системой упражнений, направленных на развитие навыков устной и письменной речи. Аутентичный учебный материал позволяет решать учебно-методические проблемы на современном уровне.

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PREFACE

Настоящее пособие включает тексты по актуальной на сегодняшний день проблемам физики и нанотехнологий.

Пособие предназначено для студентов факультета нано- и биомедицинских технологий.

Целью данного пособия является формирование навыка чтения и перевода научной литературы, а также развитие устной речи.

Данное пособие помогает подготовить студентов к самостоятельной работе со специальной литературой, обучить устным формам общения по научной тематике на материале предложенных специальных текстов.

Пособие состоит из разделов, посвященных нанотехнологиям, механике, каждый из которых содержит тексты и упражнения. Раздел “Supplementary reading“ служит материалом для расширения словарного запаса и дальнейшего закрепления навыков работы с текстами по специальности.

Пособие предназначено как для аудиторных занятий, так и для внеаудиторной практики.

1. Light

Part 1

Exercise I .

Say what Russian words help to guess the meaning of the following words: visual, signal, information, process, moment, categories, generate, position, spherical, region

Exercise II

Make sure you know the following words and word combinations.
luminous objects (1), illuminated objects (1), generate (1), smooth surfaces (4), specular reflection (4), rough surfaces (4), diffuse reflection (4), light beam (4), bundle (4), glare (5)

Light

The bottom line is: without light, there would be no sight. The visual ability of humans and other animals is the result of the complex interaction of light, eyes and brain. We are able to see because light from an object can move through space and reach our eyes. Once light reaches our eyes, signals are sent to our brain, and our brain deciphers the information in order to detect the appearance, location and movement of the objects we are sighting at. The whole process, as complex as it is, would not be possible if it were not for the presence of light. If you were to turn off the room lights for a moment and then cover all the windows with black paper to prevent any entry of light into the room, then you would notice that nothing in the room would be visible. There would be objects present that were capable of being seen. There would be eyes present that would be capable of detecting light from those objects. There would be a brain present that would be capable of deciphering the information sent to it. But there would be no light! The room and everything in it would look black. The appearance of black is merely a sign of the absence of light. When a room full of objects (or a table, or a sky) looks black, then the objects are not generating nor reflecting light to your eyes.

The objects that we see can be placed into one of two categories: luminous objects and illuminated objects. Luminous objects are objects that generate their own light. Illuminated objects are objects that are capable of reflecting light to our eyes. The sun is an example of a luminous object, while the moon is an illuminated object. During the day, the sun generates sufficient light to illuminate objects on Earth. The blue skies, the white clouds, the green grass, the colored leaves of fall, the neighbor's house, and the car approaching the intersection are all seen as a result of light from the sun (the luminous object) reflecting off the illuminated objects and traveling to our eyes. Without the light from the luminous objects, these illuminated objects would not be seen. During the evening when the Earth has rotated to a position where the light from the sun can no longer reach our part of the Earth (due to its inability to bend around the spherical shape of the Earth), objects on Earth appear black (or at least so dark that we could say they are nearly black). In the absence of a street light, the neighbor's house can no longer be seen; the grass is no longer green, but rather black; the leaves on the trees are dark; and were it not for the headlights of the car, it would not be seen approaching the intersection. Without luminous objects generating light that propagates through space to illuminate non-luminous objects, those non-luminous objects cannot bee seen. (1)

None of us generate light in the visible region of the electromagnetic spectrum. We are not brilliant objects (please take no offense) like the sun; rather, we are illuminated objects like the moon. We make our presence visibly known by reflecting light to the eyes of those who look our way. It is only by reflection that we, as well as most of the other objects in our physical world, can be seen. And if reflected light is so essential to sight, then the very nature of light reflection is a worthy topic of study among students of physics. And in this lesson and the several that follow, we will undertake a study of the way light reflects off objects and travels to our eyes in order to allow us to view them. (2)

In physics class, the behavior of light is often studied by observing its reflection off of plane (flat) mirrors. Mirrors are typically smooth surfaces, even at the microscopic levels. As such, they offer each individual ray of light the same surface orientation. But quite obviously, mirrors are not the only types of objects which light reflects off of. Most objects which reflect light are not smooth at the microscopic level. Your clothing, the walls of most rooms, most flooring, skin, and even paper are all rough when viewed at the microscopic level. (3)

Reflection off of smooth surfaces such as mirrors or a calm body of water leads to a type of reflection known as specular reflection. Reflection off of rough surfaces such as clothing, paper, and the asphalt roadway leads to a type of reflection known as diffuse reflection.

Whether the surface is microscopically rough or smooth has a tremendous impact upon the subsequent reflection of a beam of light. A light beam can be thought of as a bundle of individual light rays which are traveling parallel to each other. Each individual light ray of the bundle follows the law of reflection. If the bundle of light rays is incident upon a smooth surface, then the light rays reflect and remain concentrated in a bundle upon leaving the surface. On the other hand, if the surface is microscopically rough, the light rays will reflect and diffuse in many different directions. For each type of reflection, each individual ray follows the law of reflection. However, the roughness of the material means that each individual ray meets a surface which has a different orientation. The normal line at the point of incidence is different for different rays. Subsequently, when the individual rays reflect off the rough surface according to the law of reflection, they scatter in different directions. The result is that the rays of light are incident upon the surface in a concentrated bundle and are diffused upon reflection. (4)

There are several interesting applications of this distinction between specular and diffuse reflection. One application pertains to the relative difficulty of night driving on a wet asphalt roadway compared to a dry asphalt roadway. Most drivers are aware of the fact that driving at night on a wet roadway results in an annoying glare from oncoming headlights. The glare is the result of the specular reflection of the beam of light from an oncoming car. Normally a roadway would cause diffuse reflection due to its rough surface. But if the surface is wet, water can fill in the crevices and smooth out the surface. Rays of light from the beam of an oncoming car hit this smooth surface, undergo specular reflection and remain concentrated in a beam. The driver perceives an annoying glare caused by this concentrated beam of reflected light. (5)

A second application of the distinction between diffuse and specular reflection pertains to the field of photography. Many people have witnessed in person or have seen a photograph of a beautiful nature scene captured by a photographer who set up the shot with a calm body of water in the foreground. The water (if calm) provides for the specular reflection of light from the subject of the photograph. Light from the subject can reach the camera lens directly or it can take a longer path in which it reflects off the water before traveling to the lens. Since the light reflecting off the water undergoes specular reflection, the incident rays remain concentrated (instead of diffusing). The light is thus able to travel together to the lens of the camera and produce an image (an exact replica) of the subject which is strong enough to perceive in the photograph. (6)

Exercise III.

Find paragraphs, dealing with the following:

spectrum, calm, tremendous, parallel, scatter, dry, headlights, crevices, photography, lens

Exercise IV.

Answer the following questions:

1. What is light?

2. Which tool can be used to separate white light into different colors?

3. What do we call the colors that make up white light?

4. What do light rays do as they pass from one transparent material to another?

5. What does a lens do?

6. The law of reflection involves two light rays. What are they?

7. What three things can light rays travel through?

8. What is a material through which light can pass but will be scattered in different directions?

9. What types of surfaces reflect light well and why: light coloured and smooth or dull and dark or dark coloured and smooth?

10. Choose the color of the wall to make it reflect as much light as possible: black or white or yellow.

11. How are shadows formed?

12. How do we see a tree?

13. What is an example of refraction: light reflecting in a mirror or red and blue light mixed together or light bending through a glass prism or any opaque materials?

14. What does "luminous" mean?

15. Through what substance does the air travel faster: wood or glass or water or air? Explain your choice.

16. Which type of electromagnetic radiation has the highest frequencies?

Exercise V.

Fill in the gaps according to the text.

1. Once light reaches our eyes, signals are sent to our……., and our brain deciphers the information in order to detect the appearance, location and movement of the objects we are sighting at.
2. The appearance of black is merely a sign of the ……….of light.
3. …………..objects are objects that generate their own light.
4. Illuminated objects are objects that are capable of ………light to our eyes.
5. Mirrors are typically ………surfaces, even at the microscopic levels.
6. Your clothing, the walls of most rooms, most flooring, skin, and even paper are all …………when viewed at the microscopic level.
7. Reflection off of smooth surfaces such as mirrors or a calm body of water leads to a type of reflection known as……….. reflection**.**
8. Reflection off of rough surfaces such as clothing, paper, and the asphalt roadway leads to a type of reflection known as…………. reflection**.**
9. A light …………can be thought of as a bundle of individual light rays which are traveling parallel to each other.

10. Light from the subject can reach the camera ………directly or it can take a longer path in which it reflects off the water before traveling to the lens.

Exercise VI .

Make up sentences of your own with the following word combinations:

turn off lights , cover something with, to prevent any entry of light into, detect light, decipher the information, bend around, in the absence of, take no offense, make our presence visibly known by, it is only by reflection that

Exercise VII.

Determine whether the statements are true or false. Correct the false statements:

1. The visual ability of humans and other animals is the result of the complex interaction of light and eyes.
2. We are able to see because light from an object can move through space and reach our eyes.
3. The objects that we see can be placed into one of three categories.
4. The sun is an example of a illuminated object, while the moon is an luminous object.
5. Without the light from the luminous objects, these illuminated objects would not be seen.
6. Without luminous objects generating light that propagates through space to illuminate non-luminous objects, those non-luminous objects cannot bee seen.
7. All of us generate light in the visible region of the electromagnetic spectrum.

8. In physics class, the behavior of light is often studied by observing its reflection off of plane (flat) mirrors.
9. Most objects which reflect light are smooth at the microscopic level.
10. If the surface is microscopically rough, the light rays will reflect and diffuse in one direction.

Exercise VIII .

Match the words to the definitions in the column on the right:

glare	a picture produced using a camera
replica	objects that are capable of reflecting light to our eyes
luminous objects	an exact copy of an object
camera	reflection off of rough surfaces such as clothing, paper, and the asphalt roadway
perceive	a curved piece of glass, plastic, or other transparent material, used in cameras, glasses, and scientific equipment, that makes objects seem closer, larger, smaller, etc.
specular reflection	a device for taking photographs or making films or television programmes
Illuminated objects	reflection off of smooth surfaces such as mirrors or a calm body of

	water
lens	to see something or someone, or to notice something that is obvious
diffuse reflection	strong and dazzling light
photograph	objects that generate their own light

Exercise IX.

Summarize the article "Light."

Part 2

Exercise I.

Identify the part of speech the words belong to.

ability, complex, interaction, decipher, process, possible, presence, prevent, entry

Exercise II .

Form adjective from the following words:

absence (1), offense (2), normal (4), incidence (4), difficulty (5)

Exercise III.

Find synonyms to the following words. Translate them into Russian:

to be seen (1), watch (1), diagnose (1), site (1), filled (1), cast back (2), lustrous (2), produce (2), enough (2), rotate (2)

Exercise IV .

Find antonyms to the following words. Translate them into Russian:

inability(1), simple(1), encode(1), reveal(1), exit(1), overlook(1), optional (3), unworthy(3), enormously(5), tiny(5)

Exercise V .

Match the words to make word combinations:

asphalt	light
oncoming	shape
luminous	world
specular	surfaces
electromagnetic	bundle
physical	roadway
street	reflection
spherical	objects
smooth	spectrum
concentrated	headlights

Exercise VI.

QUIZ:

1. A light ray has an angle of incidence of 34º. The reflected ray will make what angle with the reflecting surface?

A. 0º
B. 34º
C. 56º
D. 66º
E. 74º

3. The critical angle for diamond (n = 2.42) submerged in water (n = 1.33) is

A. 33°
B. 49°
C. 24°
D.17°
E.Does not exist

4. Calculate the index of refraction for an object in which light travels at 1.97 x 108 m/s.
A. 1.97 m/s
B. 0.66 m/s
C. 1.52 m/s
D. 1.95
E. 1.52

5. The critical angle of zircon is 31°. Which of the following incident angles would result in total internal reflection?
A. 17°
B. 34°
C. 42°
D. A and C
E. B and C

6. When a light ray travelling in glass is incident on an air surface,
A. It will refract away from the normal
B. Some of the light may be reflected
C. All of the light may be reflected
D. All of A, B, and C
E. Two of A, B, and C

7. Light travels from medium X into medium Y. Medium Y has a higher index of refraction. Consider each statement below:(i) The light travels faster in X. (ii) The light will bend towards the normal. (iii) The light will speed up. (iv) The light will bend away from the normal.
A. (ii)

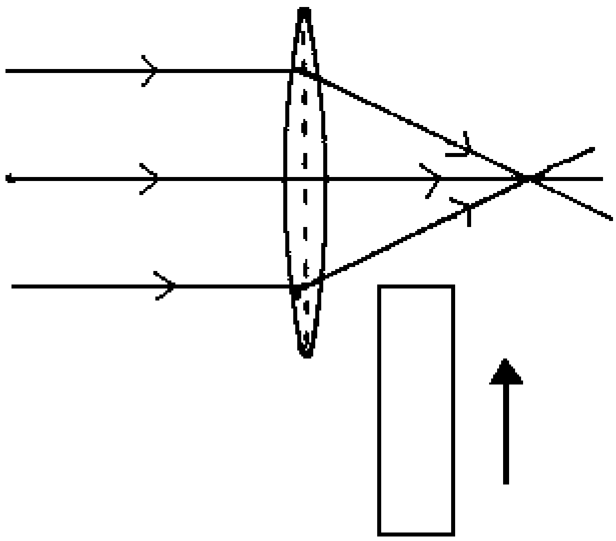
B. (iii) and (iv)
C. (i)
D. (i) and (ii)
E. (ii), (iii), and (iv)

8. For a converging lens, a light ray that is travelling parallel to the principal axis refracts
A. Through the principal focus
B. Through the secondary focus
C. Through the optical centre
D. Parallel to the principal axis
E. In line with the principal focus

9. A object is placed between f and 2f for a diverging lens. The image will be located
A. Between f and 2f
B. Between the lens and f
C. Farther than 2f
D. A or B
E. There is insufficient information to answer the question.

10. Light that travels into the eye passes through several parts to get to the retina. The correct order is
A. Cornea, vitreous humour, lens, pupil
B. Lens, cornea, pupil, vitreous humour
C. Cornea, lens, pupil, vitreous humour
D. Pupil, cornea, lens, vitreous humour
E. Cornea, pupil, lens, vitreous humour

11. A block of glass is pushed into the path of the light, as shown below. The point where the light rays cross will..............



A. Stay in the same place
B. Move to the left
C. Move to the right
D. Shift up
E. Shift down

12. The focal length of a converging lens is 15 cm. An object is placed 45 cm away from the lens. The image will be
A. Smaller and real
B. Larger and real
C. The same size and real
D. Smaller and virtual
E. Larger and virtual

13.The focal length of a diverging lens is 12 cm. An object is placed 5.0 cm away from the lens. The image will be
A.Smaller and real
B. Larger and real
C. The same size and real
D. Smaller and virtual
E. Larger and virtual

14. The rate at which light falls on a surface is called
A. luminance.

B. luminous flux.
C. capacitance.
D. none of the above.

15. The speed of light in a special type of a precious gem is 1.5×10^{8} m/s. What is this gem's index of refraction?
A. 0.5
B. 1.5
C. 2
D. 2.5

16. The bending of light as it travels from one medium to another is called
A. reflection.
B. refraction.
C. inspection.
D. none of the above.

17. Which type of electromagnetic radiation has the highest frequencies?
A. Light
B. X-ray
C. Ultra-violet
D. Infra-red

18. Plastic has an index of refraction of 1.46. If a ray of light hits a sheet of plastic at an angle of 27.3°, what will the angle of refraction be?
A. 18.3°
B. 21.9°
C. 34.5°
D. None of the above

2. Heat and Thermal Energy

Part 1

Exercise I .

Say what Russian words help to guess the meaning of the following words: thermodynamics, system, fact, molecule, million, planet, temperature, identical, mass, gas

Exercise II

Make sure you know the following words and word combinations.
heat source (3), heat sink (3), temperature gradient (3), convection (4), conductive medium (5), electromagnetic waves (5), thermal radiation (5), conduction (6), thermal conductor (7), thermal expansion (8)

Heat and Thermal Energy.

When scientists originally studied thermodynamics, they were really studying heat and thermal energy. Heat can do anything: move from one area to another, get atoms excited, and even increase energy. Did we say energy? That's what heat is. When you increase the heat in a system, you are really increasing the amount of energy in the system. Now that you understand that fact, you can see that the study of thermodynamics is the study of the amount of energy moving in and out of systems. (1)

Now all of this energy is moving around the world. You need to remember that it all happens on a really small scale. Energy that is transferred is at an atomic level. Atoms and molecules are transmitting these tiny amounts of energy. When heat moves from one area to another, it's because millions of atoms and molecules are working together. Those millions of pieces become the energy flow throughout the entire planet. Heat moves from one system to another because of differences in the temperatures of the systems. If you have two identical systems with equal temperatures, there will be no flow of energy. When you have two systems with different temperatures, the energy will start to flow. Air mass of high pressure forces large numbers of molecules into areas of low pressure. Areas of high temperature give off energy to areas with lower temperature. There is a constant flow of energy throughout the universe. Heat is only one type of that energy. (2)

Another big idea in thermodynamics is the concept of energy that changes the freedom of molecules. For example, when you change the state of a system (solid, liquid, gas), the atoms and/or molecules have different arrangements and degrees of freedom to move. That increase in freedom is called entropy. Atoms are able to move around more and there is more activity. That increase in freedom (also called randomness) is an increase in entropy. If there is a temperature difference in a system, heat will naturally move from high to low temperatures. The place you find the higher temperature is the heat source. The area where the temperature is lower is the heat sink. When examining systems, scientists measure a number called the temperature gradient. The gradient is the change in temperature divided by the distance. The units are degrees per centimeter. If the temperature drops over a specific distance, the gradient is a negative value. If the temperature goes up, the gradient has a positive value. The greater the gradient, the more energy will be exchanged. (3)

Convection is the way heat is transferred from one area to another when there is a "bulk movement of matter." It is the movement of huge amounts of material, taking the heat from one area and placing it in another. Warm air rises and cold air replaces it. The heat has moved. It is the transfer of heat by motion of objects. Convection occurs when an area of hot water rises to the top of a pot and gives off energy. Another example is warm air in the atmosphere rising and giving off energy. They are all examples of convection. The thing to remember is that objects change position. (4)

When the transfer of energy happens by radiation, there is no conductive medium (such as in space). That lack of medium means there is no matter there for the heat to pass through. Radiation is the energy carried by electromagnetic waves (light). Those waves could be radio waves, infrared, visible light, UV, or Gamma rays. Heat radiation is usually found in the infrared sections of the EM spectrum. If the temperature of an object doubles (in Kelvin), the thermal radiation increases 16 times. Therefore, if it goes up four times, it increases to 32 times the original level.

Scientists have also discovered that objects that are good at giving off thermal radiation are also good at absorbing the same energy. Usually the amount of radiation given off by an object depends on the temperature. The rate at which you absorb the energy depends on the energy of the objects and molecules surrounding you. (5)

Conduction is a situation where the heat source and heat sink are connected by matter. As we discussed before, the heat flows from the source down the temperature gradient to the sink. It is different from convection because there is no movement of large amounts of matter, and the transfers are through collisions. The source and the sink are connected.(6)

If you touch an ice cream cone, the ice cream heats up because you are a warmer body. If you lie on a hot sidewalk, the energy moves directly to your body by conduction. When scientists studied good thermal radiators, they discovered that good thermal conductors are also good at conducting electricity. So when you think of a good thermal conductor, think about copper, silver, gold, and platinum. (7)

Now you need to think about states of matter a little bit. We'll start with gases. The idea behind thermal expansion is that gases expand as the temperature increases. If you have a balloon and you heat up the contents, the balloon will get larger. Scientists use the term ideal gas law to describe this activity. Liquids expand and contract, too, but there is a lot less change than in gases. Scientists say they have a smaller thermal expansion coefficient. As you can probably figure out, solids expand and contract the least of all the states of matter. The expansion coefficient is different for each piece of matter. It is a unique value, just like specific heat capacity. (8)

The opposite of expansion is contraction. If things expand with the addition of heat, it makes sense that they contract when heat is removed.

If you remove enough heat from a gas it will become a liquid. Liquids can turn into solids with further cooling. What happens when you remove almost all of the energy from a system? Scientists use the terms absolute zero to describe a system that has no kinetic energy. When there is no kinetic energy in a system, all molecular motion stops. It seems that even the atoms begin to merge at these low temperatures. Physicists have recently created the Bose-Einstein state of matter that has a small group of atoms with nearly all of the kinetic energy taken out of the system. (9)

How do you make heat? You could burn things (chemical reactions), or you could rub things together (friction). When you burn things, thermal energy is released. Thermal energy is measured in calories. For example, when you burn wood, you release 3000 calories for each gram of wood. When you burn an apple, it creates only 600 calories. The amount of energy released is directly related to the chemical bonds that are broken and formed. If you use that idea, there is more energy available when you break and rebond the atoms in wood, than when you do the same to an apple. (10)

We just talked about friction. Heat is also created because of inefficiency. When a car engine runs, a lot of heat is given off. Much of that heat is the result of the friction and inefficiency in the running motor. When you lift something and your muscle contracts, you are only 25% efficient. Seventy-five percent of the energy is lost to heat. (11)

Exercise III.

Find paragraphs, dealing with the following:

entire, universe, concept, pot, radio, double, matter, sidewalk, cone, balloon

Exercise IV.

Answer the following questions:

1. Heat is the random movement of what? Give the definition of heat.
2. What type of radiation is associated with heat? How does heat travel?
3. What do we call materials that let heat pass through them easily?
4. Which of these is a good thermal insulator: steel, iron or polystyrene?
5. Liquids expand when heated except what: alcohol or water or oil or juice?
6. What is absolute zero?
7. Explain the term "thermal equlibrium"
8. At what temperature is Fahrenheit equal to Centigrade?
9. Which of the following would contain particles with the greatest average kinetic energy: water vapor from your breath on a freezing nigh or a snowball held in your gloved hand or a cup of hot chocolate or ice on a pond? Explain your choice.
10. As you move close to a campfire, you notice the air seems warmer the nearer you get to the fire. Without touching it, you can tell that the

fire is quite hot compared to its surroundings. Which scientific concept allows you to feel that something is hot without touching it?

11. When warm water rises in a lake and cold water descends, what is happening?

12. Which scientific term is "the measure of the average kinetic energy of all the particles in a sample of matter"?

13. Which has a greater thermal energy, a cup of 50°C water, or a bathtub of 50°C water? Explain your choice.

14. As a thunderhead builds, warm air at the Earth's surface rises and cold air high aloft sinks downward. What heat transfer process is occurring here?

15. A gardener carefully places her outdoor thermometer in a shady location out of direct sunlight, so that it doesn't give incorrectly high readings. What method of heat transfer is she trying to avoid?

16. Which type of heat transfer (if any) would be possible in the vacuum of space? Radiation, conduction, convection or no heat transfer at all? Give your explanation.

Exercise V.

Fill in the gaps according to the text.

1. There is a constant flow of……… throughout the universe.

2. That increase in freedom is called…………

3. The place you find the higher temperature is the…………

4. The …………is the change in temperature divided by the distance.

5. When the transfer of energy happens by…………, there is no conductive medium (such as in space).

6. Radiation is the energy carried by……………waves (light).

7. Scientists have also discovered that objects that are good at giving off thermal radiation are also good at …………the same energy.

8. If you lie on a hot sidewalk, the energy moves directly to your body by…………….

9. The ……………coefficient is different for each piece of matter.

10. The opposite of expansion is……………..

Exercise VI .

Make up sentences of your own with the following word combinations: at an atomic level, rise to the top of , give off energy, heat up, rub things together, be measured in, make sense

Exercise VII.

Determine whether the statements are true or false. Correct the false statements:

1. Air mass of low pressure forces large numbers of molecules into areas of high pressure.
2. The area where the temperature is higher is the heat sink.
3. The greater the gradient, the less energy will be exchanged.
4. If the temperature drops over a specific distance, the gradient is a positive value.
5. If the temperature goes up, the gradient has a negative value.

6. Warm air rises and cold air replaces it.

7. Convection occurs when an area of cold water rises to the top of a pot and gives off energy.

8. Heat radiation is usually found in the infrared sections of the EM spectrum.

9. If the temperature of an object doubles (in Kelvin), the thermal radiation decreases 16 times.

10. Usually the amount of radiation given off by an object depends on the temperature.

Exercise VIII .

Match the words to the definitions in the column on the right:

heat sink	an increase or decrease in the magnitude of a property (e.g. temperature, pressure, or concentration) observed in passing from one point or moment to another
convection	the energy carried by electromagnetic waves
entropy	the place you find the higher temperature
wave	the power from something such as electricity or oil that can dowork, such as providing light and heat
heat source	the movement of something in one direction

heat	the area where the temperature is lower
gradient	the pattern in which some types of energy, such as sound, light, and heat, are spread or carried
energy	a thermodynamic quantity representing the unavailability of a system's thermal energy for conversion into mechanical work, often interpreted as the degree of disorder or randomness in the system
flow	the flow of heat through a gas or a liquid
radiation	the quality of being hot or warm, or the temperature of something

Exercise IX.

Summarize the article "Heat and Thermal Energy."

Part 2

Exercise I.

Identify the part of speech the words belong to.

thermodynamics, heat, happen, scale, atomic, tiny, freedom, solid, liquid, entropy

Exercise II .

Form verbs from the following words:

activity (3), conductive(5), radiation(5), expansion (8), addition (9)

Exercise III.

Find synonyms to the following words. Translate them into Russian: quantity (1), bit (2), equivalent (2), load (2), continuous (2), theory (3), hard (3), split (3), interval (3), memorize (4)

Exercise IV .

Find antonyms to the following words. Translate them into Russian: forget (2), partial (2), finish (2), restriction (3), general (3), exceptionally (5), insufficient (9), contraction (9), start (9), separate (9)

Exercise V .

Match the words to make word combinations:

thermal	value
chemical	gradient
thermal	pressure
heat	rays
Gamma	energy
energy	bonds
temperature	expansion
conductive	flow
low	source
negative	medium

Exercise VI.

QUIZ:

1. The two temperature scales with the same interval step size are the

A. Celsius and Fahrenheit.

B. Fahrenheit and Kelvin.

C. Kelvin and Celsius.

D. This does not exist.

2. Substance A has a higher specific heat than substance B. With all other factors equal, which requires the most energy to heat equal masses of A and B to the same temperature?

A. Substance A

B. Substance B

C. Both require the same amount of heat.

D. Answer depends on the density of each substance.

3. With all other factors equal, the most likely to burn your mouth when taken directly from an oven is a food with

A. higher specific heat.

B. lower specific heat.

C. specific heat is not important in this situation.

D. more information needed.

4. A large and a small container of water with the same temperature have

A. the same total amounts of internal energy.

B. the same amounts of internal and external energy.

C. different amounts of heat.

D. the same amounts of all forms of energy

5. Anytime a temperature difference occurs, you can expect

A. cold to move to where it is warmer.

B. energy movement from higher temperature regions.

C. no energy movement unless it is warm enough, at least above the freezing temperature.

D. energy movement flowing slowly from cold to warmer regions

6. As you go to higher elevations above sea level the boiling point of water

A. decreases.

B. increases.

C. stays the same.

D. changes with the initial temperature of the water.

7. Increasing the rate of heating under a pot of boiling water will

A. increase the temperature of the boiling water.

B. increase the rate of boiling, but not the temperature

C. increase both the rate of boiling and the temperature of the boiling water

D. all of the above

8. As a solid goes through a phase change to a liquid, heat is absorbed and the temperature

A. increases

B. decreases

C. remains the same

D. fluctuates

9. The transfer of energy from molecule to molecule is called

A. convection.

B. radiation

C. conduction

D. equilibrium

10. No water vapor is added to or removed from a sample of air that is cooling, so the relative humidity of this sample of air will

A. remain the same.

B. be lower.

C. be higher.

D. depend on the temperature.

11. Concerning the Celsius and Fahrenheit thermometer scales,

A. the Fahrenheit is more accurate since it has more degrees than the Celsius scale.

B. there is nothing special about either scale.

C. the Celsius is more precise since it has the same degree interval size as the Kelvin scale

D. the Celsius is less precise since degrees below freezing are negative values

12. Numbers on both the Fahrenheit and Celsius scales would have no meaning without

A. conversion equations.

B. Kelvin temperature scale

C. two fixed points to which they are compared

D. none of the above

13. Suppose the volume of gasoline in your gas tank expands with warming temperatures. Do you now have more gasoline?

A. No, you still have the same mass of gasoline

B. Yes, the volume increased and so has the mass

C. No, the mass decreased as the volume increased to maintain the density

D. Yes, the density and the volume increased

14. Compared to cooler air, warm air can

A. hold more water vapor.

B. less water vapor.

C. be the same amount of water vapor.

D. depend on the exact temperature at the time

15. A heat pump is able to produce cooler temperatures because the refrigerant is

A. a cool liquid that is pumped through the system

B. evaporated in the cool part by reduction of pressure

C. condensed in the cool part by the action of the compressor

D. a working fluid that produces thermal energy from electrical

16. The reason a ship floats is because

A. all hollow objects can float

B. the buoyant force is greater then the weight of the ship

C. its lack of natural buoyancy is compensated for by the drive of the engines

D. the buoyant force is not great enough to drag it under the water

17. The second law of thermodynamics,

A. is unrelated to the concept of entropy

B. implies that there is no upper limit ideally to the efficiency of a heat engine and theoretically all the heat from a source could be transformed into mechanical energy

C. is not obeyed by biological systems, only physical systems

D. means that the entropy of an isolated system cannot decrease

18. Which of the following substances would you expect to have the highest density at room temperature and atmospheric pressure?

A. aluminum

B. gasoline

C. mercury

D. iron

19. The concept of the arrow of time

A. is a meaningless concept when it comes to pure physics

B. is totally unrelated to the notion of entropy

C. is another way of saying that all systems are totally reversible

D. suggests that in some cases events can only go in one direction and not all many-particle systems are reversible

20. A 500-kg block has the dimensions 1 m × 2 m × 3 m. Its density is

A. 12.4 kg/m3

B. 83.33 kg/m3

C. 56.6 kg/m3

D. 343.8 kg/m3

21. A block that is 2 m × 2 m × 2m that weighs 600 kg will exert how much pressure on a horizontal surface?

A. 1.47 kPa

B. 1,470Pa

C. 2,940Pa

D. 2.9 Pa

22. A heat engine absorbs heat at a temperature of 116°C and exhausts heat at a temperature of 85°C. Its maximum efficiency is

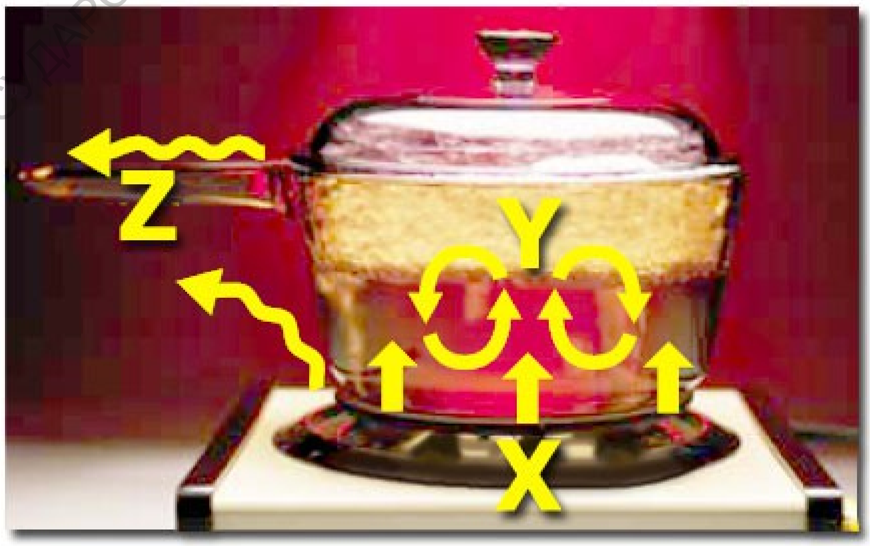
A. 3 percent

B. 8 percent

C.16 percent

D. 42 percent

23. The following photograph shows a transparent pot of boiling water. When you grab the handle to left the pot from the stove, you notice the handle is very warm. What is the best description of how the handle became warm?



A. Conduction of heat through the glass material of the pot

B. Radiation of thermal energy through the glass material of the pot

C. Convection of thermal energy through the glass material of the pot

D. Conduction of thermal energy through the water into the glass material of the pot

24. On cold winter nights a mother places a portable heater in her toddler's bedroom. The heater does not have a fan to bow hot air, it only has simple metal coils that get very hot. What method of heat transfer does this type of heater use?

A. Radiation

B. Induction

C. Convection

D. Conduction

3. Thermodynamic Laws

Part 1

Exercise I .

Say what Russian words help to guess the meaning of the following words: status, reaction, efficient, section, chaos, term, balance

Exercise II

Make sure you know the following words and word combinations.
Adiabatic (6), internal energy (6), isovolumic (6), isobaric (6), isothermal (6), thermal equilibrium (6), randomness (7), enthalpy (7), entropy (7), reversibility (8)

Thermodynamic Laws

A thermodynamic system is one that interacts and exchanges energy with the area around it. The exchange and transfer need to happen in at least two ways. At least one way must be the transfer of heat. If the thermodynamic system is "in equilibrium," it can't change its state or status without interacting with its environment. Simply put, if you're in equilibrium, you're a "happy system," just minding your own business. You can't really do anything. If you do, you have to interact with the world around you. (1)

The zeroth law of thermodynamics will be our starting point. We're not really sure why this law is the zeroth. We think scientists had "first" and "second" for a long time, but this new one was so important it should come before the others. And voila! Law Number Zero! Here's what it says: When two systems are sitting in equilibrium with a third system, they are also in thermal equilibrium with each other. In English: systems "One" and "Two" are each in equilibrium with "Three." That means they each have the same energy content as "Three". But if THAT'S true, then all the values found in "Three", match those in both "One" and "Two". It's obvious, then, that the values of "One" and "Two" must ALSO match. This means that "One" and "Two" have to be in equilibrium with each other. (2)

The first law of thermodynamics is a little simpler. The first law states that when heat is added to a system, some of that energy stays in the system and some leaves the system. The energy that leaves does work on the area around it. Energy that stays in the system creates an increase in the internal energy of the system. In English: you have a pot of water at room temperature. You add some heat to the system. First, the temperature and energy of the water increases. Second, the system releases some energy and it works on the environment (maybe heating the air around the water, making the air rise). (3)

The second law of thermodynamics explains that it is impossible to have a repeating process that converts heat completely into work. It is also impossible to have a process that transfers heat from cool objects to warm objects without using work. In English: that first part of the law says no reaction is 100% efficient. Some amount of energy in a reaction is always lost to heat. Also, a system can not convert all of its energy to working energy. The second part of the law is more obvious. A cold body can't heat up a warm body. Heat naturally wants to flow from warmer to cooler areas. Heat wants to flow and spread out to areas with less heat. If heat is going to move from cooler to warmer areas, it is going against what is “natural”, so the system must put in some work for it to happen. (4)

A Closer Look at the First Law

Remember the first law of thermodynamics? It described the conservation of energy. When you have a system and it changes, there are four ways it can change its energy. We'll talk about those four ways of changing energy in this section. (5)

Four Thermodynamic Systems

Adiabatic describes a system that changes with no transfer of heat in or out. If a system expands adiabatically, then the internal energy (heat) of the system usually decreases. This is because you did some work to expand the system, and that had to come from the heat energy of the system (since no heat energy can enter the system). The second type of system is isovolumic. You can probably see the term 'volum' in there. Iso usually stands for constant. Put them together and you get a system that changes, but the volume stays constant. These types of changes do not produce any work on the environment. The third type of system is isobaric. You've seen the prefix iso before, and the suffix baric refers to pressure. This system changes but keeps a constant pressure. All of the change is in the volume of gas in the system. As you blow air into a balloon, the volume will increase, but the pressure will stay the same. As energy is put into the system, temperature or volume may increase (or both), but there will be no increase in temperature. The fourth type of system is isothermal. We're talking about systems that change in every way but their temperature. You would say that these systems are in thermal equilibrium. You would see that the pressure and volume change. As energy is put in the system, the pressure or volume will increase (or both), but there will be no increase in temperature. (6)

A Closer Look at the Second Law

We're going to talk about the second law of thermodynamics here. Scientists use a word called entropy to describe the degree of freedom (randomness) in a system. Remember, there are two words in thermodynamics: entropy, which talks about randomness, and enthalpy, which is a measure of the heat energy in a system. Big difference. Heat flows from hot areas to cold, not the other way. If its energy is to flow from cold to hot, it needs additional energy. Heat is also conserved when energy transfer occurs. That conservation means that when you look at the energy of both systems at the beginning of the reaction and at the end, the total energy amounts are equal. Energy has moved from one area to another, but the total remains the same. The second law also considers the entropy of a system. Entropy is a measure of the amount of disorder (chaos) in a system. A good rule of thumb is the more disorder you have, the more energy you have. (7)

You might hear the term reversibility. Scientists use the term reversibility to describe systems that are in equilibrium with themselves and the environment around them. When a system is in equilibrium, any change that occurs in one direction is balanced by an equal change in the opposite direction. Reversibility means that effects can be reversed. This implies that the system is isolated (nothing is interfering, nothing entering or leaving). Overall, their effect and change on the system are zero. (8)

Even at Equilibrium

So you've got a system at equilibrium. Look closely and you'll find certain qualities. You'll find that in these systems the heat transfer is due to temperature differences. You'll also discover that wild changes do not happen in an isolated system. To get big changes, you need energy. When you're at equilibrium, there is no gain or loss of energy. Lastly, you'll see that there is no friction involved in the system. If friction occurred, heat would be created and work would be needed to overcome the friction. That work would take energy out of the system. (9)

<u>**Exercise III**</u>.

Find paragraphs, dealing with the following:

conservation, enthalpy, chaos, thumb, gain, imply

<u>**Exercise IV**</u>.

Answer the following questions:

1. What does thermodynamics study?

2. What is possible because of the second law about the direction of energy flow?

3. What is the name of the process where energy is transferred during molecular collisions? Give your examples.

4. What happens to the heat in an irreversible process?

5. Which of the following best illustrates the Second Law of Thermodynamics: a cold frying pan heats up faster when placed in the microwave rather than the stove or a hot frying pan cools down when it is taken off the kitchen stove? Explain your choice.

6. What does the area under the temperature-entropy curve (T – s curve) of any thermodynamic process represent?

7. In general, entropy increases are expected to accompany which of the following processes: crystalizing a solid out of solution or melting a solid or condensing a gas to a liquid or freezing a liquid?

8. What do we call the thermodynamic quantity that indicates whether a reaction is spontaneous or not?

9. What thermodynamic quantity is related to the randomness or disorder of the universe?

10. Which one of the following answer choices is the best description of the situation in which individual atoms have enough energy to vibrate in place but not enough energy to move (translate) in space: frozen or evaporating or boiling or absolute zero?

11. How much of the electrical energy that flows through a common light bulb becomes heat energy? (the percentage)

12. When muscles contract, chemical energy is converted to mechanical energy with the loss of heat. What law of thermodynamics is applied in this example?

13. What is an adiabatic process?

14. You are cooking scrambled eggs in a cast iron frying pan, and you have noticed the handle has grown rather warm. What type of heat transfer is demonstrated within the pan in this example?

15. What does it mean for a process to be quasi-equilibrium? Why is it necessary that a system be quasi-equilibrium (i.e. quasi-static) before applying many of the thermodynamics relations to that system?

16. Explain how a refrigerator works in terms of energy, heat and work.

Exercise V.

Fill in the gaps according to the text.

1. A thermodynamic system is one that interacts and exchanges ……….. with the area around it.
2. If the thermodynamic system is "in …………," it can't change its state or status without interacting with its environment.
3. The second law of ………..explains that it is impossible to have a repeating process that converts heat completely into work.
4. …………describes a system that changes with no transfer of heat in or out.
5. The second type of system is ………...

6. The third type of system is …………...
7. The fourth type of system is ………….
8. Scientists use a word called ……… to describe the degree of freedom (randomness) in a system.
9. Entropy is a measure of the amount of …………in a system.
10. Scientists use the term ………..to describe systems that are in equilibrium with themselves and the environment around them.

Exercise VI .

Make up sentences of your own with the following word combinations: to be in equilibrium with each other, heat up, in thermal equilibrium, in one direction, in the opposite direction, to get big changes, at the beginning of, at the end, to overcome the friction, take energy out of

Exercise VII.

Determine whether the statements are true or false. Correct the false statements:

1. The first law states that when heat is added to a system, some of that energy stays in the system and some leaves the system.
2. Energy that stays in the system creates an increase in the internal energy of the system.
3. A cold body can heat up a warm body.
4. Heat naturally wants to flow from cooler to warmer areas.
5. Heat wants to flow and spread out to areas with more heat.
6. If a system expands adiabatically, then the internal energy (heat) of the system usually increases.

7. All of the change is in the volume of gas in the system.
8. As you blow air into a balloon, the volume will decrease, but the pressure will stay the same.
9. If its energy is to flow from cold to hot, it needs additional energy.
10. A good rule of thumb is the more disorder you have, the less energy you have.

Exercise VIII .

Match the words to the definitions in the column on the right:

adiabatic	the temperature that is normal inside a building, neither very hot nor very cold
interact	a system that changes, but the volume stays constant
enthalpy	act in such a way as to have an effect on each other
balloon	relating to or denoting a process or condition in which heat does not enter or leave the system concerned
isobar	A thermodynamic quantity equivalent to the total heat content of a system. It is equal to the internal energy of the system plus the product of pressure and volume.
reversibility	a curve on a diagram joining points representing states of equal temperature
randomness	a large bag filled with hot air or gas to make it rise in the air, typically one carrying a basket for passengers

isovolumic	systems that are in equilibrium with themselves and the environment around them
isotherm	a curve or formula representing a physical system at constant pressure
room temperature	happening, done, or chosen by chance rather than according to a plan

Exercise IX.

Summarize the article "Thermodynamic Laws."

Part 2

Exercise I.

Identify the part of speech the words belong to.

interact, thermal, obvious, internal, release, convert, conservation, expand, enter, isovolumic

Exercise II .

Form adverbs from the following words:

part (4), efficient (4), obvious (5), adiabatic (6), constant (6), equal (7), total (7), certain (9)

Exercise III.

Find synonyms to the following words. Translate them into Russian:

interchange (1), easily (1), spot (2), correspond (2), clarify (4), transform (4), by nature (4), protection (5), perhaps (6), save (6)

Exercise IV .

Find antonyms to the following words. Translate them into Russian: doubtful (2), short (2), obscure (2), partially (4), possible (4), found (4), never (4), abnormal (4), beginning (7), partial (7)

Exercise V .

Match the words to make word combinations:

isolated	temperature
constant	point
thermodynamic	equilibrium
internal	pressure
thermal	system
room	law
starting	energy

Exercise VI.

QUIZ:

1. In an irreversible process, there is a..................

A. loss of heat

B. no loss of heat

C. gain of heat

D. no gain of heat

2. The amount of heat required to raise the temperature of unit mass of a gas through one degree at constant pressure is called specific heat at constant pressure.

A. True

B. False

3. The state of a substance whose evaporation from its liquid state is complete, is known as

A. vapour

B. perfect gas

C. air

D. steam

4. When a gas is heated, change takes place in

A. pressure

B. volume

C. temperature

D. all of these

5. Which of the following is an intensive property of a thermodynamic system?

A. Volume

B. Temperature

C. Mass

D. Energy

6. The main cause for the irreversibility is

A. mechanical and fluid friction

B. unrestricted expansion

C. heat transfer with a finite temperature difference

D. all of the above

7. According to kinetic theory of gases, the velocity of molecules …....................with the increase in temperature.

A. remains constant

B. increases

C. decreases

8. For an ideal gas enthalpy

A. Increases with pressure

B. Decreases with pressure.

C. Independent of changes in pressure

D. all the above

9. According to First law of thermodynamics,

A. total internal energy of a system during a process remains constant

B. total energy of a system remains constant

C. work done by a system is equal to the heat transferred by the system

D. internal energy, enthalpy and entropy during a process remains constant

10. When a gas is heated at constant volume

A. its temperature will increase

B. its pressure will increase

C. both temperature and pressure will increase

D. neither temperature nor pressure will increase

11. Which of the following is the correct statement of the second law of thermodynamics?

A. It is impossible to construct an engine working on a cyclic process, whose sole purpose is to convert heat energy into work.

B. It is impossible to transfer heat from a body at a lower temperature to a higher temperature, without the aid of an external source.

C. There is a definite amount of mechanical energy, which can be obtained from a given quantity of heat energy.

D. all of the above

12. Those substances which have so far not been resolved by any means into other substances of simpler form are called

A. atoms

B. elements

C. compounds

D. molecules

13. When two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other. This statement is called

A. Zeroth law of thermodynamics

B. First law of thermodynamics

C. Second law of thermodynamics

D. Kelvin Planck's law

14. The specific heat at constant volume is

A. the amount of heat required to raise the temperature of 1 kg of water through one degree

B. any one of the above

C. the amount of heat required to raise the temperature of unit mass of gas through one degree, at constant pressure

D. the amount of heat required to raise the temperature of unit mass of gas through one degree, at constant volume

15. In an isothermal process

A. there is no change in enthalpy

B. there is no change in internal energy
C. there is no change in temperature
D. all of these

16. The area under the temperature-entropy curve (T – s curve) of any thermodynamic process represents

A. heat rejected

B. heat absorbed
C. either heat absorbed or heat rejected
D. none of these

SUPPLEMENTARY READING

Thermodynamics. Real-life applications

Hot and "Cold"

It was stated that there is no such thing as "cold"—a statement hard to believe for someone who happens to be in Buffalo, New York, or International Falls, Minnesota, during a February blizzard. Certainly, cold is real as a sensory experience, but in physical terms, cold is not a "thing"—it is simply the absence of heat.

People will say, for instance, that they put an ice cube in a cup of coffee to cool it, but in terms of physics, this description is backward: what actually happens is that heat flows from the coffee to the ice, thus raising its temperature. The resulting temperature is somewhere between that of the ice cube and the coffee, but one cannot obtain the value simply by averaging the two temperatures at the beginning of the transfer.

For one thing, the volume of the water in the ice cube is presumably less than that of the water in the coffee, not to mention the fact that their differing chemical properties may have some minor effect on the interaction. Most important, however, is the fact that the coffee did not simply merge with the ice: in transferring heat to the ice cube, the molecules in the coffee expended some of their internal kinetic energy, losing further heat in the process.

Cooling machines

Even cooling machines, such as refrigerators and air conditioners, actually use heat, simply reversing the usual process by which particles are heated. The refrigerator pulls heat from its inner compartment—the area where food and other perishables are stored—and transfers it to the region outside. This is why the back of a refrigerator is warm.

Inside the refrigerator is an evaporator, into which heat from the refrigerated compartment flows. The evaporator contains a refrigerant—a gas, such as ammonia or Freon 12, that readily liquifies. This gas is released into a pipe from the evaporator at a low pressure, and as a result, it evaporates, a process that cools it. The pipe takes the refrigerant to the compressor, which pumps it into the condenser at a high pressure. Located at the back of the refrigerator, the condenser is a long series of pipes in which pressure turns the gas into liquid. As it moves through the condenser, the gas heats, and this heat is released into the air around the refrigerator.

An air conditioner works in a similar manner. Hot air from the room flows into the evaporator, and a compressor circulates refrigerant from the evaporator to a condenser. Behind the evaporator is a fan, which draws in hot air from the room, and another fan pushes heat from the condenser to the outside. As with a refrigerator, the back of an air conditioner is hot because it is moving heat from the area to be cooled. Thus, cooling machines do not defy the principles of heat discussed above; nor do they defy the laws of thermodynamics that will be discussed at the conclusion of this essay. In accordance with the second law, in order to move heat in the reverse of its usual direction, external energy is required. Thus, a refrigerator takes in energy from a electric power supply (that is, the outlet it is plugged into), and extracts heat. Nonetheless, it manages to do so efficiently, removing two or three times as much heat from its inner compartment as the amount of energy required to run the refrigerator.

Transfers of Heat

It is appropriate now to discuss how heat is transferred. One must remember, again, that in order for heat to be transferred from one point to another, there must be a difference of temperature between those two points. If an object or system has a uniform level of internal thermal energy—no matter how "hot" it may be in ordinary terms—no heat transfer is taking place.

Heat is transferred by one of three methods: conduction, which involves successive molecular collisions; convection, which requires the motion of hot fluid from one place to another; or radiation, which involves electromagnetic waves and requires no physical medium for the transfer.

Conduction

Conduction takes place best in solids and particularly in metals, whose molecules are packed in relatively close proximity. Thus, when one end of an iron rod is heated, eventually the other end will acquire heat due to conduction. Molecules of liquid or nonmetallic solids vary in their ability to conduct heat, but gas—due to the loose attractions between its molecules—is a poor conductor.

When conduction takes place, it is as though a long line of people are standing shoulder to shoulder, passing a secret down the line. In this case, however, the "secret" is kinetic thermal energy. And just as the original phrasing of the secret will almost inevitably become garbled by the time it gets to the tenth or hundredth person, some energy is lost in the transfer from molecule to molecule. Thus, if one end of the iron rod is sitting in a fire and one end is surrounded by air at room temperature, it is unlikely that the end in the air will ever get as hot as the end in the fire.

Incidentally, the qualities that make metallic solids good conductors of heat also make them good conductors of electricity. In the first instance, kinetic energy is being passed from molecule to molecule, whereas in an electrical field, electrons—freed from the atoms of which they are normally a part—are able to move along the line of molecules. Because plastic is much less conductive than metal, an electrician will use a screwdriver with a plastic handle. Similarly, a metal pan typically has a handle of wood or plastic.

Convection

There is a term, "convection oven," that is actually a redundancy: all ovens heat through convection, the principal means of transferring heat through a fluid. In physics, "fluid" refers both to liquids and gases —anything that tends to flow. Instead of simply moving heat, as in conduction, convection involves the movement of heated material—that is, fluid. When air is heated, it displaces cold (that is, unheated) air in its path, setting up a convection current.

Convection takes place naturally, as for instance when hot air rises from the land on a warm day. This heated air has a lower density than that of the less heated air in the atmosphere above it, and, therefore, is buoyant. As it rises, however, it loses energy and cools. This cooled air, now more dense than the air around it, sinks again, creating a repeating cycle.

The preceding example illustrates natural convection; the heat of an oven, on the other hand, is an example of forced convection—a situation in which some sort of pump or mechanism moves heated fluid. So, too, is the cooling work of a refrigerator, though the refrigerator moves heat in the opposite direction.

Forced convection can also take place within a natural system. The human heart is a pump, and blood carries excess heat generated by the body to the skin. The heat passes through the skin by means of conduction, and at the surface of the skin, it is removed from the body in a number of ways, primarily by the cooling evaporation of moisture—that is, perspiration.

Radiation

If the Sun is hot—hot enough to severely burn the skin of a person who spends too much time exposed to its rays—then why is it cold in the upper atmosphere? After all, the upper atmosphere is closer to the Sun. And why is it colder still in the empty space above the atmosphere, which is still closer to the Sun? The reason is that in outer space there is no medium for convection, and in the upper atmosphere, where the air molecules are very far apart, there is hardly any medium. How, then, does heat come to the Earth from the Sun? By radiation, which is radically different from conduction or convection. The other two involve ordinary thermal energy, but radiation involves electromagnetic energy.

A great deal of "stuff" travels through the electromagnetic spectrum, discussed in another essay in this book: radio waves, microwaves for television and radar, infrared light, visible light, x rays, gamma rays. Though the relatively narrow band of visible-light wavelengths is the only part of the spectrum of which people are aware in everyday life, other parts—particularly the infrared and ultraviolet bands—are involved in the heat one feels from the Sun. (Ultraviolet rays, in fact, cause sunburns.)

Heat by means of radiation is not as "other-worldly" as it might seem: in fact, one does not have to point to the Sun for examples of it. Any time an object glows as a result of heat—as for example, in the case of firelight—that is an example of radiation. Some radiation is emitted in the form of visible light, but the heat component is in infrared rays. This also occurs in an incandescent light bulb. In an incandescent bulb, incidentally, much of the energy is lost to the heat of infrared rays, and the efficiency of a fluorescent bulb lies in the fact that it converts what would otherwise be heat into usable light.

The Laws of Thermodynamics

Having explored the behavior of heat, both at the molecular level and at levels more easily perceived by the senses, it is possible to discuss the laws of thermodynamics alluded to throughout this essay. These laws illustrate the relationships between heat and energy examined earlier, and show, for instance, why a refrigerator or air conditioner must have an external source of energy to move heat in a direction opposite to its normal flow.

The story of how these laws came to be discovered is a saga unto itself, involving the contributions of numerous men in various places over a period of more than a century. In 1791, Swiss physicist Pierre Prevost (1751-1839) put forth his theory of exchanges, stating correctly that all bodies radiate heat. Hence, as noted earlier, there is no such thing as "cold": when one holds snow in one's hand, cold does not flow from the snow into the hand; rather, heat flows from the hand to the snow.

Seven years later, an American-British physicist named Benjamin Thompson, Count Rumford (1753) was boring a cannon with a blunt drill when he noticed that this action generated a great deal of heat. This led him to question the prevailing wisdom, which maintained that heat was a fluid form of matter; instead, Thompson began to suspect that heat must arise from some form of motion.

Carnot's Engine

The next major contribution came from the French physicist and engineer Sadi Carnot (1796-1832). Though he published only one scientific work, *Reflections on the Motive Power of Fire* (1824), this treatise caused a great stir in the European scientific community. In it, Carnot made the first attempt at a scientific definition of work, describing it as "weight lifted through a height." Even more important was his proposal for a highly efficient steam engine.

A steam engine, like a modern-day internal combustion engine, is an example of a larger class of machine called heat engine. A heat engine absorbs heat at a high temperature, performs mechanical work, and, as a result, gives off heat a lower temperature. (The reason why that temperature must be lower is established in the second law of thermodynamics.)

For its era, the steam engine was what the computer is today: representing the cutting edge in technology, it was the central preoccupation of those interested in finding new ways to accomplish old tasks. Carnot, too, was fascinated by the steam engine, and was determined to help overcome its disgraceful inefficiency: in operation, a steam engine typically lost as much as 95% of its heat energy.

In his *Reflections,* Carnot proposed that the maximum efficiency of any heat engine was equal to (T H -T L)/T H , where T H is the highest operating temperature of the machine, and T L the lowest. In order to maximize this value, T L has to be absolute zero, which is impossible to reach, as was later illustrated by the third law of thermodynamics.

In attempting to devise a law for a perfectly efficient machine, Carnot inadvertently proved that such a machine is impossible. Yet his work influenced improvements in steam engine design, leading to levels of up to 80% efficiency. In addition, Carnot's studies influenced Kelvin —who actually coined the term "thermodynamics"—and others.

The First Law of Thermodynamics

During the 1840s, Julius Robert Mayer (1814-1878), a German physicist, published several papers in which he expounded the principles known today as the conservation of energy and the first law of thermodynamics. As discussed earlier, the conservation of energy shows that within a system isolated from all outside factors, the total amount of energy remains the same, though transformations of energy from one form to another take place.

The first law of thermodynamics states this fact in a somewhat different manner. As with the other laws, there is no definitive phrasing; instead, there are various versions, all of which say the same thing. One way to express the law is as follows: Because the amount of energy in a system remains constant, it is impossible to perform work that results in an energy output greater than the energy input.

For a heat engine, this means that the work output of the engine, combined with its change in internal energy, is equal to its heat input. Most heat engines, however, operate in a cycle, so there is no net change in internal energy.

Earlier, it was stated that a refrigerator extracts two or three times as much heat from its inner compartment as the amount of energy required to run it. On the surface, this seems to contradict the first law: isn't the refrigerator putting out more energy than it received? But the heat it extracts is only part of the picture, and not the most important part from the perspective of the first law.

A regular heat engine, such as a steam or internal-combustion engine, pulls heat from a high-temperature reservoir to a low-temperature reservoir, and, in the process, work is accomplished. Thus, the hot steam from the high-temperature reservoir makes possible the accomplishment of work, and when the energy is extracted from the steam, it condenses in the low-temperature reservoir as relatively cool water.

A refrigerator, on the other hand, reverses this process, taking heat from a low-temperature reservoir (the evaporator inside the cooling compartment) and pumping it to a high-temperature reservoir outside the refrigerator. Instead of producing a work output, as a steam engine does, it requires a work input—the energy supplied via the wall outlet. Of course, a refrigerator does produce an "output," by cooling the food inside, but the work it performs in doing so is equal to the energy supplied for that purpose.

The Second Law of Thermodynamics

Just a few years after Mayer's exposition of the first law, another German physicist, Rudolph Julius Emanuel Clausius (1822-1888) published an early version of the second law of thermodynamics. In an 1850 paper, Clausius stated that "Heat cannot, of itself, pass from a colder to a hotter body." He refined this 15 years later, introducing the concept of entropy—the tendency of natural systems toward breakdown, and specifically, the tendency for the energy in a system to be dissipated.

The second law of thermodynamics begins from the fact that the natural flow of heat is always from a high-temperature reservoir to a low-temperature reservoir. As a result, no engine can be constructed that simply takes heat from a source and performs an equivalent amount of work: some of the heat will always be lost. In other words, it is impossible to build a perfectly efficient engine.

Though its relation to the first law is obvious, inasmuch as it further defines the limitations of machine output, the second law of thermodynamics is not derived from the first. Elsewhere in this volume, the first law of thermodynamics—stated as the conservation of energy law—is discussed in depth, and, in that context, it is in fact necessary to explain how the behavior of machines in the real world does not contradict the conservation law.

Even though they mean the same thing, the first law of thermodynamics and the conservation of energy law are expressed in different ways. The first law of thermodynamics states that "the glass is half empty," whereas the conservation of energy law shows that "the glass is half full." The thermodynamics law emphasizes the bad news: that one can never get more energy out of a machine than the energy put into it. Thus, all hopes of a perpetual motion machine were dashed. The conservation of energy, on the other hand, stresses the good news: that energy is never lost.

In this context, the second law of thermodynamics delivers another dose of bad news: though it is true that energy is never lost, the energy available for work output will never be as great as the energy put into a system. A car engine, for instance, cannot transform all of its energy input into usable horsepower; some of the energy will be used up in the form of heat and sound. Though energy is conserved, usable energy is not.

Indeed, the concept of entropy goes far beyond machines as people normally understand them. Entropy explains why it is easier to break something than to build it—and why, for each person, the machine called the human body will inevitably break down and die, or cease to function, someday.

The Third Law of Thermodynamics

The subject of entropy leads directly to the third law of thermodynamics, formulated by German chemist Hermann Walter Nernst (1864-1941) in 1905. The third law states that at the temperature of absolute zero, entropy also approaches zero. From this statement, Nernst deduced that absolute zero is therefore impossible to reach.

All matter is in motion at the molecular level, which helps define the three major phases of matter found on Earth. At one extreme is a gas, whose molecules exert little attraction toward one another, and are therefore in constant motion at a high rate of speed. At the other end of the phase continuum (with liquids somewhere in the middle) are solids. Because they are close together, solid particles move very little, and instead of moving in relation to one another, they merely vibrate in place. But they do move.

Absolute zero, or 0K on the Kelvin scale of temperature, is the point at which all molecular motion stops entirely—or at least, it virtually stops. (In fact, absolute zero is defined as the temperature at which the motion of the average atom or molecule is zero.) As stated earlier, Carnot's engine achieves perfect efficiency if its lowest temperature is the same as absolute zero; but the second law of thermodynamics shows that a perfectly efficient machine is impossible. This means that absolute zero is an unreachable extreme, rather like matter exceeding the speed of light, also an impossibility.

This does not mean that scientists do not attempt to come as close as possible to absolute zero, and indeed they have come very close. In 1993, physicists at the Helsinki University of Technology Low Temperature Laboratory in Finland used a nuclear demagnetization device to achieve a temperature of $2.8 \cdot 10\ -10$ K, or 0.00000000028K.

This means that a fragment equal to only 28 parts in 100 billion separated this temperature from absolute zero—but it was still above

0K. Such extreme low-temperature research has a number of applications, most notably with superconductors, materials that exhibit virtually no resistance to electrical current at very low temperatures.