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QUESTION 1

Four major blood types exist in the human ABO blood system: types A, B, AB, and O; and there are three alleles that code for them. The A and B alleles are codominant, and the O allele is recessive. Blood types are derived from the presence of specific polysaccharide antigens that lie on the outer surface of the red blood cell membrane. The A allele codes for the production of the A antigen; the B allele codes for the production of the B antigen; the O allele does not code for any antigen. While there are many other antigens found on red blood cell membranes, the second most important antigen is the Rh antigen. Rh is an autosomally dominant trait coded for by 2 alleles. If this antigen is present, an individual is Rh+; if it is absent, an individual is Rh-. For example, a person with type AB blood with the Rh antigen is said to be AB+. These antigens become most important when an individual comes into contact with foreign blood. Because of the presence of naturally occurring substances that closely mimic the A and B antigens, individuals who do not have these antigens on their red blood cells will form antibodies against them. This is inconsequential until situations such as blood transfusion, organ transplant, or pregnancy occur.

Erythroblastosis fetalis is a condition in which the red blood cells of an Rh+ fetus are attached by antibodies produced by its Rh- mother. Unlike ABO incompatibility, in which there are naturally occurring antibodies to foreign antigens, the Rh system requires prior sensitization to the Rh antigen before antibodies are produced. This sensitization usually occurs during the delivery of an Rh+ baby. So while the first baby will not be harmed, any further Rh+ fetuses are at risk.

The Coombs tests provide a method for determining whether a mother has mounted an immune response again her baby\\'s blood. The tests are based on whether or not agglutination occurs when Coombs reagent is added to a sample. Coombs reagent contains antibodies against the anti-Rh antibodies produced by the mother. The indirect Coombs test takes the mother\\'s serum, which contains her antibodies but no red blood cells, and mixes it with Rh+ red blood cells. Coombs reagent is then added. If agglutination occurs, the test is positive, and the mother must be producing anti-Rh antibodies. The direct Coombs test mixes the baby\\'s red blood cells with Coombs reagent. If agglutination occurs, the test is positive, and the baby\\'s red blood cells must have been attacked by its mother\\'s anti-Rh antibodies.

A woman who has never been pregnant has type B- blood. Which of the following antibodies would you expect to find in her serum?

A. Anti-B antibody

B. Anti-A antibody

C. Anti-Rh antibody

D. Both anti-A and anti-Rh antibodies

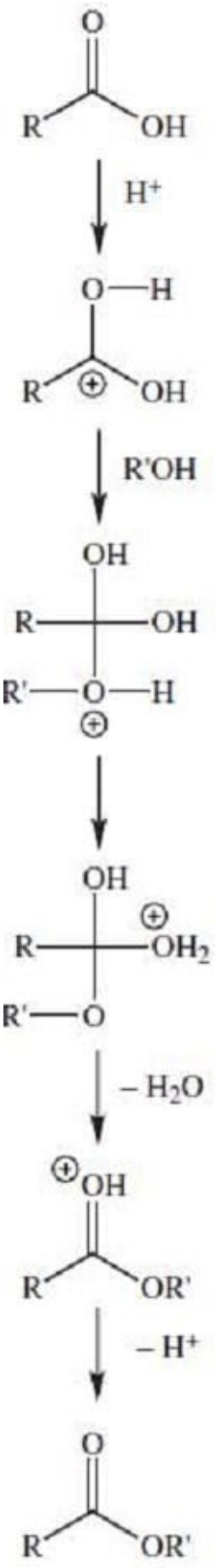
Correct Answer: B

To answer this question, you need to have an understanding of the ABO blood groups and what antigens its alleles code for. In addition, you need to have recalled from the passage that Rhimmunity requires prior sensitization, while ABO immunity does not, because of other naturally occurring antigens. Since the woman in the question has never been pregnant, it is highly unlikely that she has ever been exposed to the Rh antigen, which means that she would not pro- duce antibodies against it. So, choices C and D are wrong. Since her blood type is B, she would have anti-B antibodies, but would b expected to have anti-A antibodies because of a naturally occurring antigen that resembles the A antigen.

QUESTION 2

The mechanism for the acid-catalyzed esterification of a carboxylic acid, carried out with R\\'OH, is shown below. The tagged alcohol R\\'18OH is used to study the reaction mechanism. The resulting ester is separated from the reaction

mixture; the water from the reaction mixture is then distilled off completely and collected as a separate fraction.


O
R
OH
H+
O—H
R
OH
R'OH
OH
R
OH
R'
O
H
OH
R
OH2
R'
O
– H2O
OH
R
OR'
– H+
O
R
OR'

Which of the following alkyl halides would be most likely to react with sodium butanoate to form an ester?

A. $CH_3CH_2CH_2Cl$
B. CH_3Cl
C. $(CH_3)CHCl$
D. CH_3CH_2Cl

A. Option A

B. Option B

C. Option C

D. Option D

Correct Answer: B

In this question, you are asked to decide which alkyl halide would be most likely to react with sodium butanoate and form an ester. The reaction between a carboxylate anion and an alkyl halide is an SN2 reaction. Because this reaction involves partial bonding between the attacking nucleophile (carboxylate) and substrate (alkyl halide), it will not occur easily with bulky substrates. Bulky substrates sterically hinder the reaction, by shielding the susceptible carbon atom from the attacking nucleophile. Choice B, methyl chloride, has only hydrogen and chlorine substituents, whereas all the other choices have bulkier alkyl substituents. This makes B the least sterically hindered of all the choices, and it will therefore react most easily with sodium butanoate.

QUESTION 3

When softball players take batting practice, they often use a machine called an "automatic pitcher," which is essentially a cannon that uses air pressure to launch a projectile. In a prototype automatic pitcher, a softball is loaded into the barrel of the cannon and rests against a flat disk. That disk is locked into place, and a high air pressure is built up behind it. When the disk is released, the softball is pushed along the barrel of the cannon and ejected at a speed of V0. Figure 1 shows the batter and automatic pitcher. The angle of the barrel to the horizontal is . The unit vectors I and j point in the horizontal and vertical directions respectively.

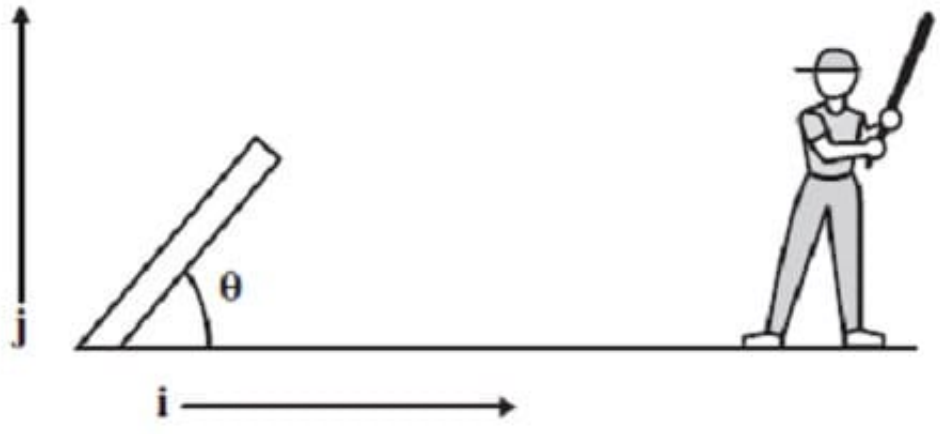


Figure 1

The height above the ground y of the softball as a function of time t is shown in Figure 2, where t = 0 at Point A, t = tB at Point B, and t = tC at Point C. The softball is ejected from the barrel of the cannon at Point A; it reaches its maximum height at Point B; and the batter hits the softball at Point C. (Note: Assume that the effects of air resistance are negligible unless otherwise stated.)

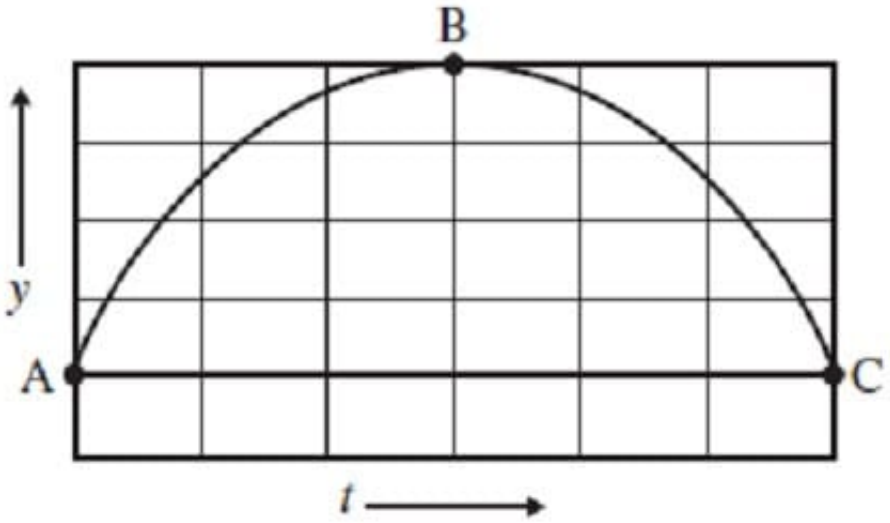


Figure 2

How does the work done by the automatic pitcher change as the angle of the barrel to the horizontal increases?

A. The work done increases, because the softball\\'s maximum height increases.

B. The work done decreases, because the softball lands closer to the cannon.

C. The work done does not change, because the air pressure behind the disk is unchanged.

D. The work done does not change, because gravity is a conservative force.

Correct Answer: C

The softball starts off at rest and acquires a speed v0 as it is launched from the cannon. The work-energy theorem states that the work done equals the change in the kinetic energy. Since the softball acquires a kinetic energy equal to (1/2) mv0 , the automatic pitcher must have done work on it. The pitcher uses air pressure, which builds up behind a disk, to do the work when the disk is released. The angle of the barrel to the horizontal will not affect this mechanism, and the softball will still be ejected with the same kinetic energy. Hence, the work done by the pitcher does not change and choice C is correct.

Although it is true that the softball\\'s maximum height increases and that the distance it lands from the cannon decreases, the work done by the pitcher does not change, so choices A and B are wrong. Although it is also true that gravity is a conservative force, it is irrelevant because the question asks about the work done by the pitcher, not the work done by gravity. Hence, choice D is incorrect as well.

QUESTION 4

Band theory explains the conductivity of certain solids by stating that the atomic orbitals of the individual atoms in the

solid merge to produce a series of atomic orbitals comprising the entire solid. The closely-spaced energy levels of the orbitals form bands. The band corresponding to the outermost occupied subshell of the original atoms is called the valence band. If partially full, as in metals, it serves as a conduction band through which electrons can move freely. If the valence band is full, then electrons must be raised to a higher band for conduction to occur. The greater the band gap between the separate valence and conduction bands, the poorer the material\\'s conductivity. Figure 1 shows the valence and conduction bands of a semiconductor, which is intermediate in conductivity between conductors and insulators.

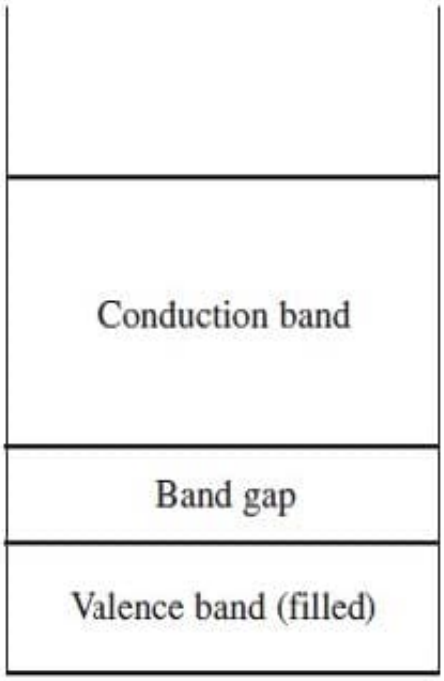


Figure 1

When silicon, a semiconductor with tetrahedral covalent bonds, is heated, a few electrons escape into the conduction band. Doping the silicon with a few phosphorus atoms provides unbonded electrons that escape more easily, increasing conductivity. Doping with boron produces holes in the bonding structure, which may be filled by movement of nearby electrons within the lattice. When a semiconductor in an electric circuit has excess electrons on one side and holes on the other, electron flow occurs more easily from the side with excess electrons to the side with holes than in the reverse direction.

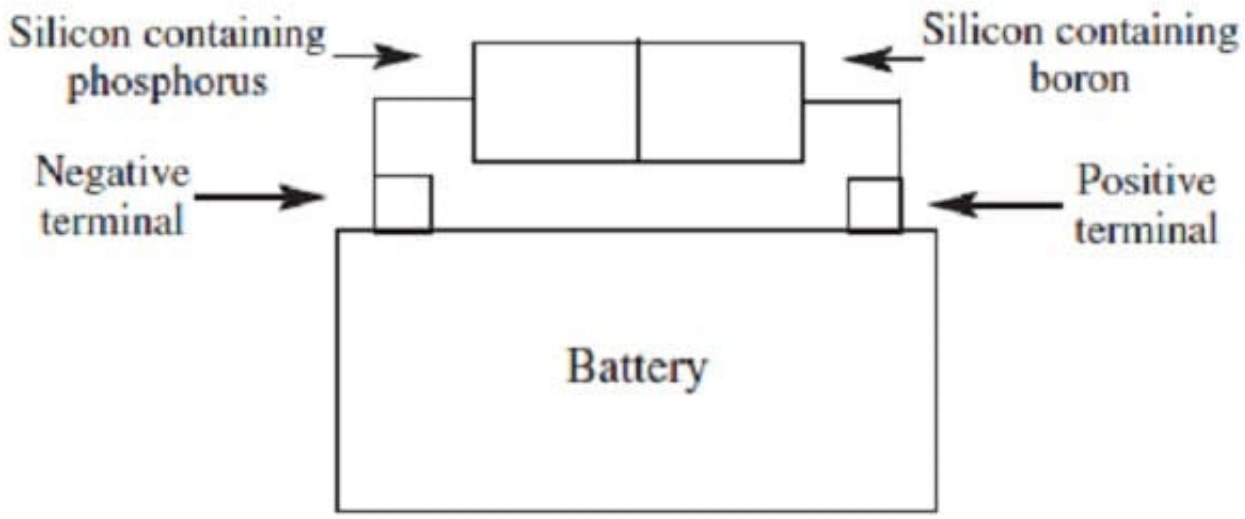


Figure 2

Why is iron a good conductor of electricity?

A. Its 3d electrons only partially fill the valence band.

B. The band gap is small.

C. The 4s and 3d orbitals form a filled valence band.

D. The energy levels of the atomic orbitals are closely separated.

Correct Answer: A

The passage mentions that metals have partially filled valence bands. This means that there are low energy unoccupied atomic orbitals in metals through which electrons may move freely. Therefore, the valence band for metals is the conduction band, and consequently, there is no band gap. Metals such as iron are good conductors of electricity because of these unoccupied low energy orbitals. All of this information is contained in the passage and requires little or no background knowledge. Choice A is therefore the correct response. Choice B is incorrect because metals, unlike semiconductors, do not have a band gap. Choice C is wrong because iron\\'s 3d orbital is not filled; it has only six electrons, not ten. Choice D is true of many solids including metals, semiconductors, and insulators, but it does not answer the question and so is incorrect.

QUESTION 5

When humans are submerged in water, the mammalian dive reflex acts to alter circulation. Heart rate decreases, blood flow to the extremities is reduced, and mean arterial blood pressure is increased. These accomodations lead to:

A. decreased oxygen demand by the tissues.

B. increased heat retention by the body.

C. decreased partial pressure of oxygen in the blood.

D. increased venous return.

Correct Answer: B

The question stem describes the effects of the mammalian dive reflex, indicating that blood flow to the extremities is reduced. This would increase heat retention of the body. Choice A is incorrect because oxygen demand by the tissues

depends on the metabolic rate of the tissues, which is not affected by changes in blood pressure, heart rate, or blood flow to the extermities. Choice C is incorrect because the dive reflex will not lead to a decrease in oxygen partial pressure.

The partial pressure of oxygen will decrease during a dive because the individual is holding their breath, not because of the accomodations of the dive reflex.

Choice D is incorrect because venous return, the amount of blood returned to the heart by the venous circulation, will not be increased. If stroke volume (the volume of blood pumped with each beat) remains constant, the decrease in heart

rate caused by the dive reflex would lead to a decrease in venous return.