INTERNATIONAL NANOTECHNOLOGY OLYMPIAD for High-School Students

FINAL EXAM

Question 1

A researcher has used 3 different nucleates for his supersaturated solution for "A" nanoparticle synthesis. Which of the following nucleates would not be formed?

1) 

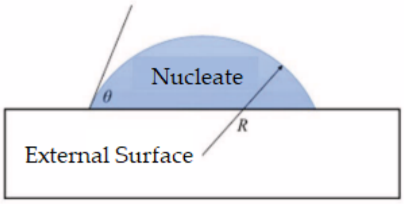
2) 

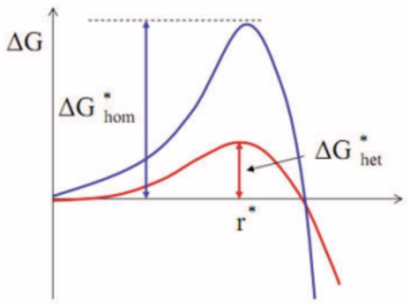
3) 

4) 

Choice 1 is the right answer.

The critical radius does not differ in the homogeneous and non-homogeneous states and is the same in both cases. Therefore, it can be stated that in the presence of the different nucleates, the critical radius remains unchanged and the same radius exists for the nucleation. Based on the pictures in the choices it is obvious that the critical radius of the formed nucleate in choice 1 is different from other choices and cannot be related to the used nucleates.





Comparison between the free energy of the homogeneous (Blue) and non-homogeneous (Red)

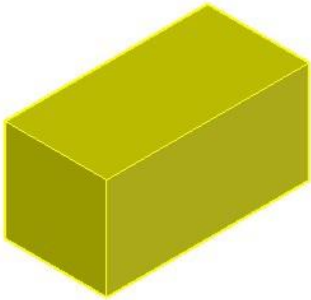
Question 2
Which of the following can increase the melting point of a nanoparticle? 1) Decreasing the particle size 2) Increasing the number of defects in the crystal lattice 3) Coating the nanoparticle surface with a protective layer 4) Increasing the surrounding pressure
Choice 3 is the right answer. By coating the surface of a nanoparticle with a protective layer, the number of free surface atoms is reduced, and consequently, more energy is required to break the bonds and melt the material.

Question 3
A student team is developing a low-cost prototype filter for removing Pb^{2+} ions from well water. They can choose between particles of 500 nm and 50 nm in size from the same adsorbent material. Which option would provide a higher adsorption capacity at the same fixed mass, and why? 1) 500 nm particles, because larger particles allow faster penetration. 2) 500 nm particles, because they are less prone to agglomeration. 3) 50 nm particles, due to higher surface-to-volume ratio and more active surface sites. 4) 50 nm particles, because bulk atoms outnumber unsaturated surface atoms.
Choice 3 is the right answer. Reducing particle size to the nanoscale significantly increases the surface-to-volume ratio; in this case, a larger fraction of atoms is located on the surface and are more active due to unsaturated bonds. This feature increases the interaction and adsorption of ions such as Pb^{2+} on the adsorbent surface.

Question 4

A researcher has synthesized a nanomaterial that can extend the lifespan of plants. This nanomaterial consists of rectangular cuboid particles with a uniform size distribution, as shown below (width = 10 nm, length = 20 nm). He intends to cover an entire football field with an area of 8,000 m^2 using this nanomaterial. What is the minimum mass of the nanomaterial required for this purpose?

Given: The density of the nanomaterial is 1.2 kg/m^3.



1) 0.024 g
2) 0.048 g
3) 0.096 g
4) 0.192 g

Choice 3 is the right answer.

A rectangular cube can be covered on the ground from two sides. One side is square, in which case the largest amount of nanomaterial is needed to cover the surface of the football field (cross-sectional area B), and the other is rectangular (cross-sectional area A), in which case the smallest amount of nanomaterial will be used. Therefore, the amount of material required if all particles of material from face A are placed on the ground is equal to:

The amount of material required if all particles of material from face A are placed on the ground:

Face area A: 20×10= 200 nm2

Area of the football field: 8000×10^{18} nm^2

Total number of nanoparticles required to cover the surface: (8×1021)/200=4×1019

The mass of the required nanomaterial can be easily calculated using the density value and calculating the volume of each particle:

Volume of each nanoparticle 20×10×10= 2000 nm^3 = $2\times10^{-24} m^3$

Mass of each nanoparticle $2\times10^{-24}\times1.2 = 2.4\times10^{-24}$ kg

The required nanoparticle mass is obtained by multiplying the total number of nanoparticles required to cover the surface (4×10^{19}) by the mass of each nanoparticle (2.4×10^{-24}) and is equal to 9.6×10-5 kg or 0.096 g.

Question 5

An industrial wastewater stream contains toxic azo dyes. A research team has proposed the use of titanium oxide nanoparticles as a photocatalyst. What is the role of these nanoparticles in wastewater treatment? What is the main limitation of this method in real wastewater treatment, and what strategy could be adopted to overcome it?

Option	Role of Nanoparticles	Limitation	Strategy
1	Generation of electron–hole pairs under sunlight irradiation	Limited light penetration in large wastewater volumes	Use of optimized light systems
2	Separation of dyes from wastewater	Activation of nanoparticles only by the visible spectrum of sunlight	Doping nanoparticles with other elements
3	Generation of electron–hole pairs under sunlight irradiation	Activation of nanoparticles only by the visible spectrum of sunlight	Doping nanoparticles with other elements
4	Separation of dyes from wastewater	Limited light penetration in large wastewater volumes	Use of optimized light systems

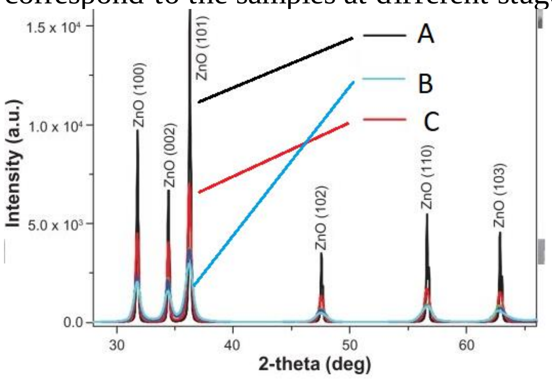
Choice 1 is the right answer.

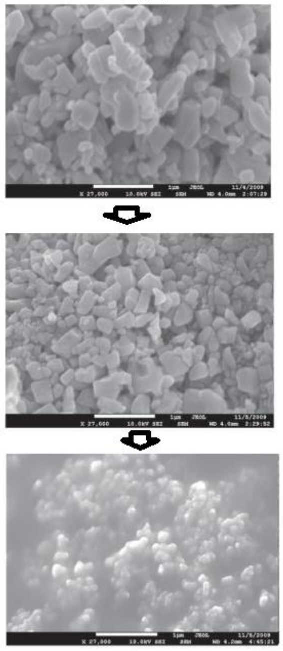
TiO_2 nanoparticles produce active electron-hole pairs under sunlight irradiation, which react with pollutants and decompose them. However, a major limitation of this method is the large volume of wastewater, which hinders effective light penetration. To overcome this challenge, the use of optimized optical systems is recommended.

Question 6
In aquaculture, the presence of heavy metals in water is a serious problem: they cause fish mortality and, upon entering the human body, lead to neurological, renal diseases and cancer. To remove these contaminants, a facility adds titanium oxide nanoparticles to the water, exposes it to ultraviolet (UV) light, and then supplies the treated water to fish ponds. For sustainable development, the company decides to use a titanium oxide/graphene oxide nanocomposite together with UV irradiation so that, besides removing heavy metals, organic pollutants are also degraded and product quality improves. After applying this nanocomposite, however, not only did fish quality not improve, but fish mortality increased. What do you think is the reason for this outcome? 1) In this nanocomposite an intermediate state in the band gap has formed that enables catalytic activity under visible light, producing free radicals in the water; whereas pure titanium oxide nanoparticles are activated only by UV light. 2) The graphene-based substrate in the nanocomposite has reduced the contact area and dispersion of the titanium oxide nanoparticles, preventing efficient removal of heavy metals. 3) The nanocomposite is unstable and immediately becomes unusable due to agglomeration upon deployment. 4) The nanocomposite is not a photocatalyst at all and is only effective for removing organic pollutants; therefore, the company's decision to change the water-treatment process was mistaken.
Choice 1 is the right answer. TiO_2-GO nanocomposite requires less energy to be excited and produce electron-hole pairs and can be excited by visible light. As a result of excitation by visible light, free radicals are created, which in water endanger the life of living organisms. (Correctness of option 1) The graphene substrate in the composite prevents phase change, destruction and agglomeration of nanoparticles, and also increases the dispersion of nanoparticles (Incorrectness of options 2 and 3). This composite has maintained its photocatalytic properties (indicating the incorrectness of option 4).

Question 7

For the synthesis of zinc oxide (ZnO) nanomaterial in a mechanical mill, a researcher sampled the material throughout the milling process. SEM images labeled D, E, and F correspond to the material at 0, 2, and 50 hours of milling, respectively. Indicate which XRD patterns correspond to the samples at different stages of the milling process, respectively.





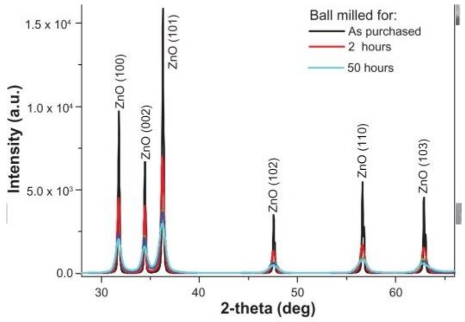
D

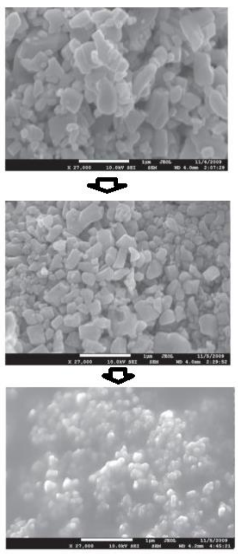
E

F

1) A→ B→ C
2) A→ C→ B
3) B→ A→ C
4) B→ C→ A

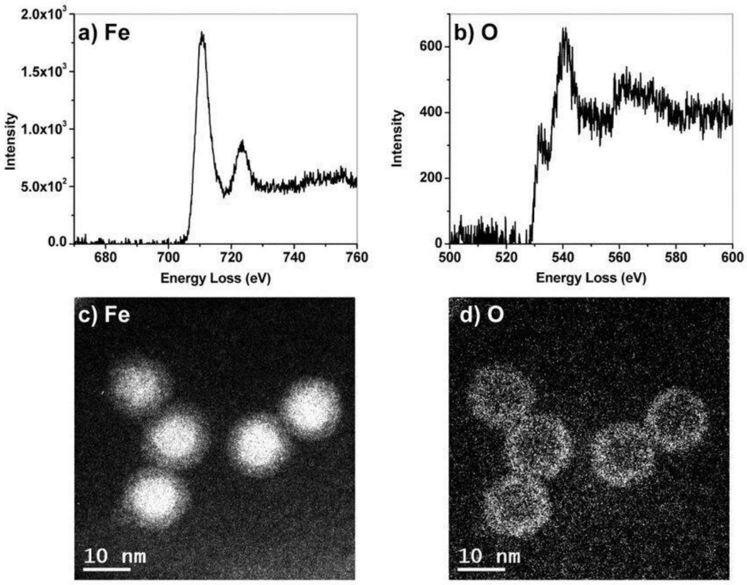
Choice 2 is the right answer.





Question 8
Suppose you are a member of an international, multidisciplinary research team designing a photocatalytic nanocomposite membrane (GO-TiO_2) to remove Pb^{2+} and Hg^{2+} ions from groundwater in rural regions with hot climates. Based on the following information, how does the GO-TiO_2 nanocomposite behave in reducing Pb^{2+} and Hg^{2+} ions under sunlight? - Conduction Band Edge (CBE) of TiO_2 (anatase phase) = – 0.5 V vs Normal Hydrogen Electrode (NHE) - Valence Band Edge (VBE) of TiO_2 (anatase phase) = + 2.7 V vs Normal Hydrogen Electrode (NHE) - Pb^{2+}/Pb = –0.13 V - Hg^{2+}/Hg = +0.85 V 1) The CBE is more positive than both reduction potentials; therefore, neither ion is reduced. 2) The CBE is only more negative than the Pb^{2+} reduction potential but not Hg^{2+}; hence, Hg^{2+} reduction is impossible without GO. 3) The CBE is more negative than both reduction potentials, so thermodynamically, reduction of both ions is possible; however, GO is essential to enhance efficiency and prevent charge recombination. 4) GO changes the thermodynamics of the redox reaction, lowering the reduction potential of Hg^{2+}, making it accessible.
Choice 3 is the right answer. The conduction band edge of TiO_2 is −0.5 with respect to the normal hydrogen electrode (NHE), which is more negative than both reduction potentials Pb^{2+}/Pb = −0.13 V and Hg^{2+}/Hg = +0.85 V; therefore, reduction of both ions is thermodynamically possible. However, GO plays an important role in improving the kinetics of the reactions, as it increases the lifetime of electrons and enhances the photocatalytic efficiency of the membrane by promoting charge separation and reducing electron–hole recombination.

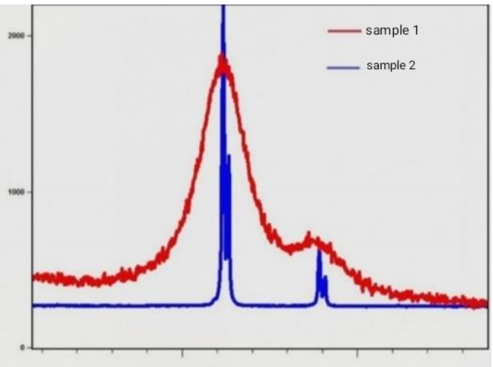
Question 9
For the removal of arsenic ions (As^{3+}) from seawater in a country with high solar irradiation, a research team is considering the following three nanomaterials: • Fe_3O_4 nanoparticles • ZnO nanoparticles • TiO_2-doped activated carbon nanocomposites To achieve the highest water-treatment efficiency, which synthesis method for the nanomaterial would you recommend? 1) Fe_3O_4 nanoparticles synthesized via the hydrothermal method 2) ZnO nanoparticles synthesized via the sol–gel method 3) Activated carbon/TiO_2 nanocomposite synthesized via the sol–gel method 4) Activated carbon/TiO_2 nanocomposite synthesized via chemical precipitation
Choice 3 is the right answer. In a country with high solar irradiation, the photocatalytic properties of the nanoparticles should be maximally utilized. For arsenic ions, magnetic Fe_3O_4 allows easy removal after adsorption, but has limited photocatalytic properties (Incorrectness of option 1). ZnO is not very suitable for ion removal (Incorrectness of option 2). The activated carbon/titanium oxide composite synthesized by the sol-gel method combines the two capabilities of arsenic adsorption and photocatalytic oxidation for organic materials (Correctness of option 3). Titanium oxide nanoparticles can be produced using the chemical precipitation method, but it is less efficient in producing nanoparticles for industrial use than the sol-gel method (Incorrectness of option 4).

Question 10
A researcher prepared zero-valent iron nanoparticles (nZVI) to reduce heavy metal content in soil and evaluated their performance using a design of experiments approach. In the initial days, the nanoparticles performed well in the test soil samples, but after a few days, their efficiency significantly decreased. To investigate the reason, the researcher performed EDS analysis along with TEM imaging on the nanoparticles recovered from the soil. EDS (Energy  Dispersive X-ray Spectroscopy) is a technique used to identify the elements present in a sample, and when combined with TEM, it provides both structural and compositional information. Based on the obtained analyses, what is the main issue with the applied nanoparticles, and what approach could be used to address it? 1) Agglomeration and clustering; application of polymers and surfactants. 2) Oxidation of zero-valent iron nanoparticles; coating with palladium. 3) Agglomeration and clustering; surface modification with noble metals. 4) Oxidation of zero-valent iron nanoparticles; stabilization with carboxymethyl cellulose.
Choice 2 is the right answer. The two main problems of zero-valent iron nanoparticles are agglomeration and oxidation. According to the results presented in the analyses, it is observed that the particles are spaced apart and their size remains at the nanometer scale, while their surface is covered with oxygen atoms, indicating the formation of oxide on their surface. Coating the surface of zero-valent iron particles with heavy metals can reduce this defect.

Question 11

For the synthesis of antibacterial nanoparticles, two samples were prepared under different conditions using the chemical precipitation method, and their XRD analyses were obtained. Based on the experimental conditions shown in the table below and the corresponding results, which sample would you select?

1) Sample 1, Due to the higher synthesis temperature, the particles exhibited better growth and a more uniform size distribution.
2) Sample 2, Due to the lower synthesis temperature, enhanced nucleation occurred, leading to the formation of smaller particles.
3) Sample 2, Owing to the lower concentration and longer synthesis duration, the formed particles were more stable and did not undergo agglomeration after synthesis.
4) Sample 1, Due to the higher concentration and shorter synthesis time, nucleation dominated over particle growth.

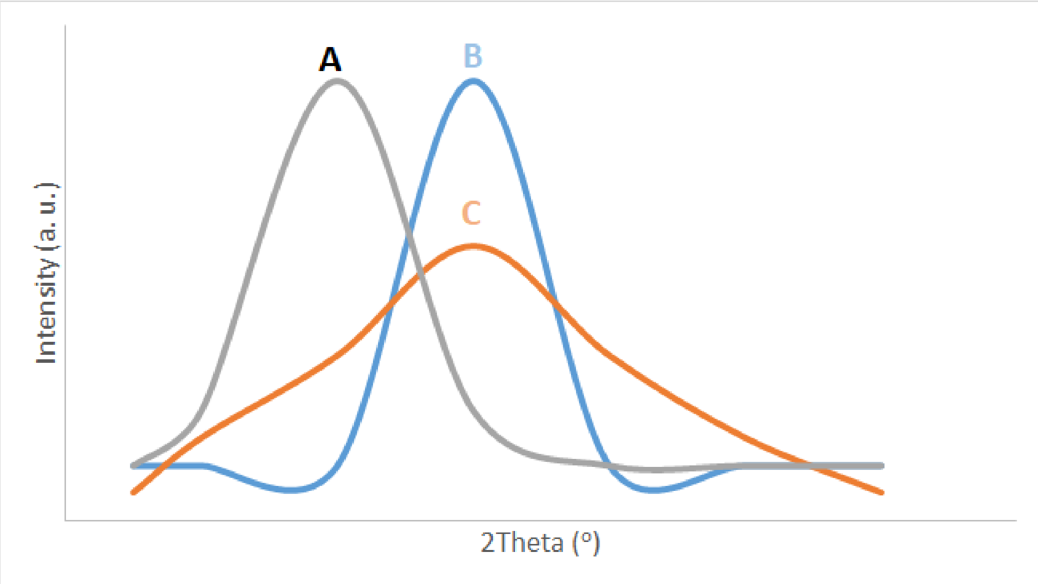


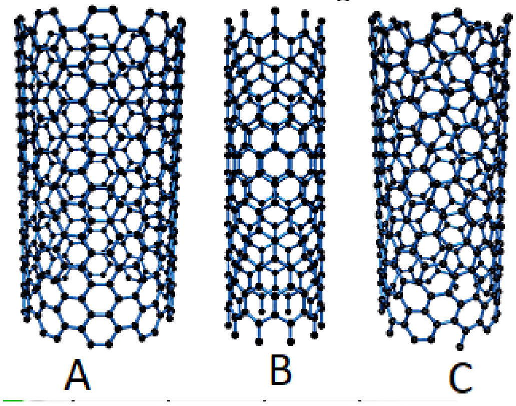
Sample	Temp. (°C)	Concentration	Synthesis Time
Sample 1	50	5 M	10 min
Sample 2	30	3 M	20 min

Choice 4 is the right answer.

The broad peak indicates smaller particle size, and the first sample has smaller particle size. As the synthesis time decreases, the nucleation step is separated from the growth, and as the concentration increases, more nuclei are produced.

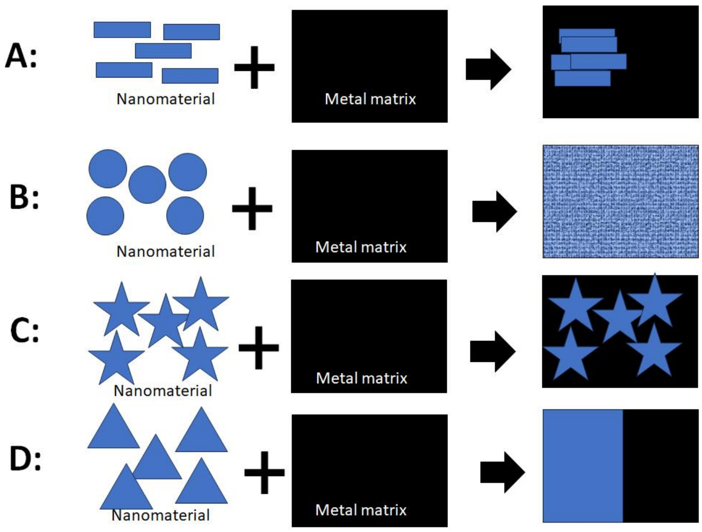
Question 12
An engineer is selecting a nanomaterial to fabricate a thin separation layer on a membrane substrate for air purification in a company. Which nanomaterial would be most suitable for this application? 1) Carbon nanotube (CNT) 2) Graphene monolayer 3) Gold nanoparticle 4) ZnO nanocomposite
Choice 2 is the right answer. Two-dimensional nanomaterials have one dimension at the nanoscale (thickness) and two free dimensions along the plane. Graphene is a prominent example of these two-dimensional structures, which is widely used in coatings and membranes as a thin active layer.

Question 13
A researcher synthesized zinc oxide (ZnO) nanomaterial in a mechanical mill and took samples of the material from the beginning to the end of the milling process. Analyses show that after 2 hours, only the spacing between the crystal planes increases. However, after 50 hours, the particle size decreases while the crystalline structure remains similar to the initial sample. The figure below shows the XRD patterns of the sampled material at 0, 2, and 50 hours. Which XRD patterns correspond to the samples at different stages of the milling process, respectively?  1) A→ B→ C 2) A→ C→ B 3) B→ A→ C 4) B→ C→ A
Choice 3 is the right answer. Considering that the interplanar spacing has increased after 2 hours, according to Bragg's law, the diffraction angle (θ) decreases. Therefore, Pattern A corresponds to the 2-hour mark, while Pattern B represents the initial stage of the mechanical milling process. Furthermore, given that particle size has decreased after 50 hours of milling, it is expected that the XRD peaks will broaden. Consequently, Pattern C is associated with the 50-hour time point.

Question 14
Which of the following carbon nanotubes can be regarded as semiconductor?  1) A 2) B 3) C 4) B and C
Choice 4 is the right answer. Armchair carbon nanotubes are always conductive due to their identical chirality components, while zigzag and chiral nanotubes can be either conductive or semiconductive.

Question 15
A suburban water services company is conducting a pilot wastewater treatment process for the textile industry, containing dye molecules and bacteria. The process is designed for minimal electricity consumption and uses solar energy. They can employ various nanomembranes and photocatalysts in the project. Which single, integrated configuration would maximize both effluent quality and energy efficiency? 1) Use high-density reverse osmosis (RO) membranes with high pressure to remove all contaminants. 2) Add TiO_2 nanoparticles in colloidal form under sunlight, followed by microfiltration to separate and recycle the particles. 3) Employ a TiO_2-coated nanofiltration membrane combined with aeration. 4) Use activated carbon (AC) with thermal regeneration in each cycle.
Choice 3 is the right answer. Photocatalytic membranes combine size/charge separation with in-situ photocatalytic degradation on the membrane surface. This reduces membrane fouling and mineralizes organic contaminants under light irradiation. Nanofiltration is particularly effective in removing dyes and polyvalent ions, and oxidation pathways can be supported by aeration of the nanomembrane. (Indicating the correctness of option 3). In contrast, the use of colloidal TiO_2 requires continuous separation and recycling of particles, which is costly and environmentally hazardous due to the high number of separation burdens and the possibility of releasing particles into the environment. (Incorrectness of option 2). RO requires significantly higher energy to operate under high pressure, and activated carbon lacks the ability of self-regeneration through photocatalytic processes (indicating the incorrectness of options 1 and 4).

Question 16
A research team is studying the removal of metal ions Pb^{2+} and Hg^{2+} from wastewater. Based on the available data (including the initial concentrations of metal contaminants and their removal rate constants), how long will it take for the effluent to meet global drinking water standards, and which cation reaches the permissible limit first? (Assume both treatment reactions follow first-order kinetics according to the formula below.) $$C = C_0 \, \boldsymbol{e^{-kt}}$$ - Initial: Pb^{2+} = 0.5 mg/L - Hg^{2+} = 0.25 mg/L - WHO standard limits: $Pb^{2+} < 0.01$ mg/L and $Hg^{2+} < 0.001$ mg/L - Pb^{2+} removal rate constant (k) = 0.15 min^{-1} and Hg^{2+} removal rate constant (k) = 0.1 min^{-1} 1) 55 minutes, Pb^{2+} 2) 26 minutes, Hg^{2+} 3) 32 minutes, Hg^{2+} 4) 11 minutes, Pb^{2+}
Choice 1 is the right answer. Pb^{2+} removal : $$C = C0 \, e^{-kt}$$ $$0.01 = 0.5 \, e^{-0.15t}$$ $$Ln\,(0.02) = -0.15\ t$$ $$T \approx 26\ min$$ Hg^{2+} removal: $$C = C0 \, e^{-kt}$$ $$0.001 = 0.25 \, e^{-0.1t}$$ $$Ln\,(0.004) = -0.\ 1\ t$$ $$T \approx 55\ min$$ So it is obvious that the water is first purified from lead and the entire purification process takes 55 minutes to make it drinkable in accordance with World Health Organization standards.

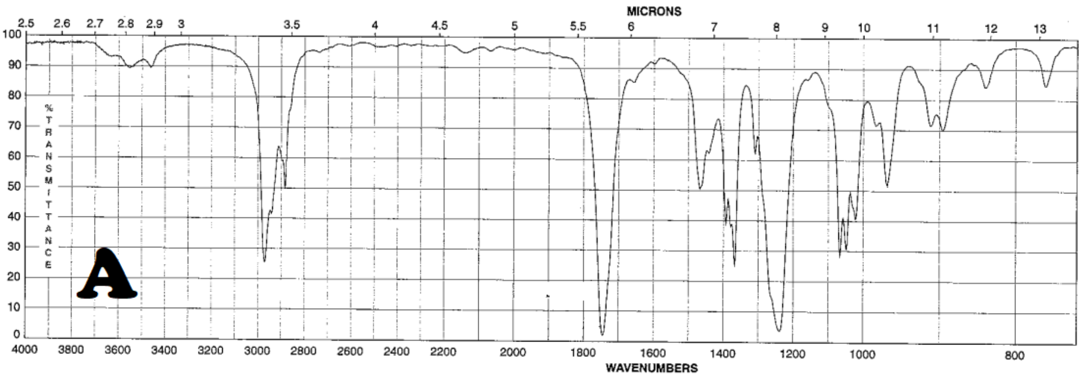
Question 17
A researcher intends to fabricate a nanocomposite by mixing nanomaterials within a metallic matrix. In which of the figures below has the researcher successfully created a proper nanocomposite?  1) A 2) B 3) C 4) D
Choice 3 is the right answer. • In nanocomposite production, both uniform distribution and uniform dispersion are needed. If the reinforcing components are present in most areas of the matrix, it is called a suitable distribution, whether the reinforcing components are separate nanoparticles or still in aggregates. However, dispersion means the separation of the nanostructures from each other and turning the aggregates into individual nanostructures. (**Choice 1** is the incorrect answer) • Another factor that can affect the final result of nanocomposite production is the potential for unwanted reactions between the reinforcing nanomaterial and the matrix, especially in metallic matrices. This is because metallic matrices often require high temperatures and pressures during the production process. At these high temperatures and pressures, there is a high possibility of a chemical reaction between the metal and the nanomaterial, which could be undesirable. For example, if single-walled carbon nanotubes are used in an aluminum matrix, a reaction might occur between the carbon nanotubes and aluminum at high temperatures and pressures, leading to the formation of aluminum carbide instead of maintaining the carbon nanotubes. When a carbon nanotube is single-walled, it is almost entirely destroyed during the reaction. (**Choice 2** is the incorrect answer) • A composite becomes a nanocomposite when at least one of its components (either the matrix or the reinforcement) has at least one dimension in the nanometer scale (below 100 nanometers). (**Choice 4** is the incorrect answer)

Question 18

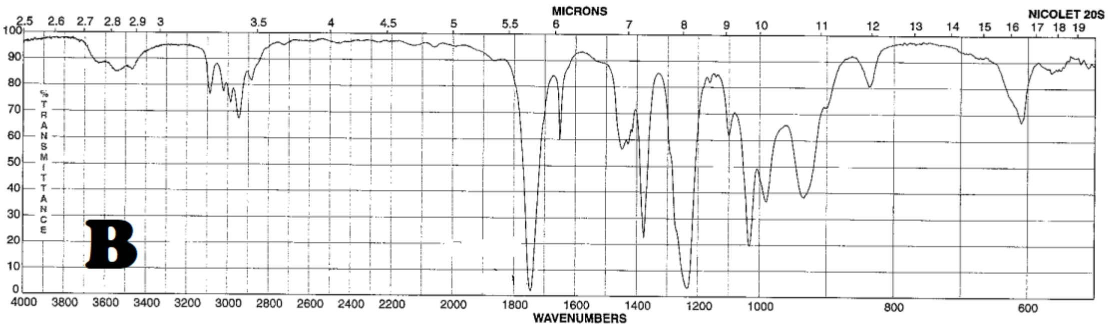
A petrochemical company's alcohol storage tank has leaked into the nearby sea due to a technical fault. To remove these contaminants from seawater, nano scientists have proposed four organic adsorbent nanomaterials. Based on the FTIR spectra of adsorbents A–D, which adsorbent is most suitable for removing alcohol contaminants?

In the FTIR spectra, the infrared light transmittance is plotted on the vertical axis from 0 (complete absorption) to 100, and the horizontal axis corresponds to the inverse of the wave energy. In FTIR spectroscopy, intermolecular bonds that are sufficiently strong behave similarly to intramolecular bonds and, due to numerous vibrations and closely spaced vibrational energy levels, can significantly influence the final spectral pattern.

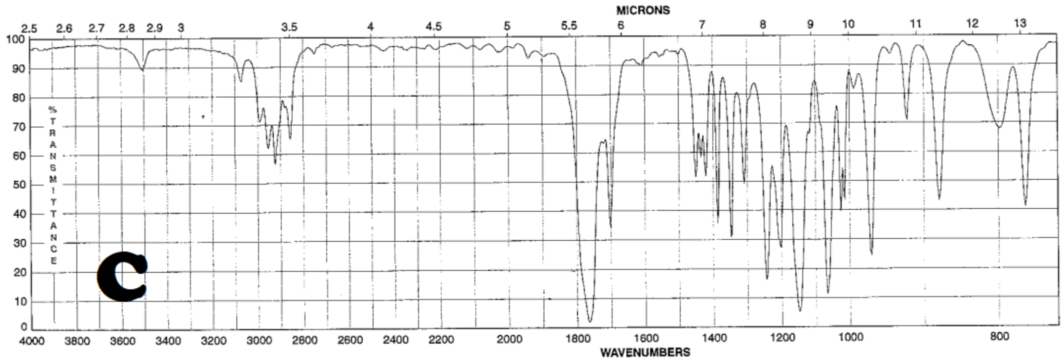
1)



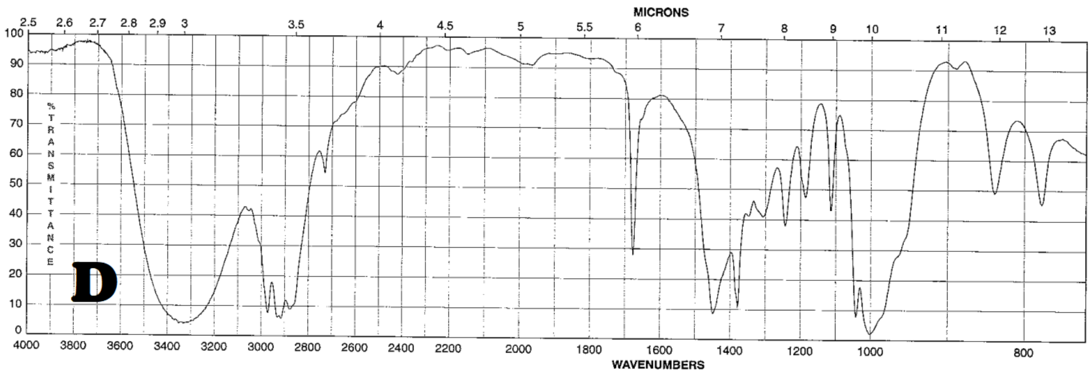
2)



3)



4)



Choice 4 is the right answer.

The question mentions that the pollutant is from the alcohol family. One of the characteristics of alcohols is their high miscibility with water due to the formation of hydrogen bonds. Given the strength of the hydrogen bond (creating peaks in the high-energy regions of the spectrum) and the greater number of vibrations of this group of intermolecular forces (the point stated in the question), the corresponding peak becomes broader and as a result, choice 4 is correct.

Question 19
A company active in the production of filters has recently entered the field of nano-filters for water purification. During the testing of one of its new products, it was observed that the water flow through the filter became significantly slower, and after some time, the product failed and lost its efficiency. In your opinion, the use of which of the following nanomaterials would be most effective in solving this problem? 1) Titanium dioxide nanoparticles 2) Zeolite nanoparticles 3) Silver nanoparticles 4) Carbon nanotubes
Choice 4 is the right answer. Polymers combined with nanoparticles such as Al_2O_3 or carbon nanotubes: These products are made by methods such as phase inversion or in situ polymerization. Benefits: - 40% increase in water flow - 60% reduction in fouling - 3-fold increase in mechanical strength

Question 20

A laboratory is testing graphene oxide (GO) membranes for desalination and intends to examine the following:

- Whether the designed membrane effectively removes sodium-containing salts from water
- Whether the membrane surface contains the expected functional groups (–OH, –COOH)
- Whether the interlayer spacing of GO changes after the desalination process

Which three techniques are most suitable for performing these analyses?

Option	Evaluate salt-removal efficiency	Characterize functional groups	Determine GO interlayer spacing
1	Water electrical conductivity measurement	FTIR	XRD
2	UV–Vis	FTIR	SEM
3	Water electrical conductivity measurement	TEM	XRD
4	UV–Vis	TEM	SEM

Choice 1 is the right answer.

TEM cannot be used to identify functional groups (Incorrectness of options 3 and 4). Also, according to the amount of peak shift in the X-ray diffraction spectrum, the change in the distance between GO sheets can be detected (Correctness of option 1). On the other hand, it should be noted that UV-Vis spectroscopy cannot detect the concentration of sodium ions because ions do not absorb in this range (Incorrectness of option 2).