

Question 1. Answer: $\sup S = 1$ and $\inf S = 0$. We show that $\sup S = 1$. Let r be any element in S . By the definition, r is rational number with $0 \leq r < 1$. Thus 1 is an upper bound of S and 0 is a lower bound of S . Let M be any upper bound of S . Then $r \leq M$ for any rational number r with $0 \leq r < 1$. In particular, $\frac{n}{n+1} \leq M$ for any positive integer n . It follows that $1 = \lim_{n \rightarrow \infty} \frac{n}{n+1} \leq M$ and so 1 is the least upper bound of S or $\sup S = 1$. Let m be any lower bound of S . Then $m \leq r$ for any rational number r with $0 \leq r < 1$. In particular, $m \leq 0$ and so 0 is the greatest lower bound of S or $\inf S = 0$. \square

Question 2. Since $\inf B$ is a lower bound of B , we have $\inf B \leq x$ for any $x \in B$ and so $\inf B \leq y$ for any $y \in A \subseteq B$. It follows that $\inf B$ is a lower bound of A . Thus $\inf B \leq \inf A$ because $\inf A$ is the greatest lower bound of A . \square

Question 3 (i). First we show that $\max\{\sup A, \sup B\}$ is an upper bound of $A \cup B$. Let z be any element in $A \cup B$. Then $z \in A$ or B . If $z \in A$, then $z \leq \sup A \leq \max\{\sup A, \sup B\}$. Otherwise, $z \in B$ and $z \leq \sup B \leq \max\{\sup A, \sup B\}$. Thus $\max\{\sup A, \sup B\}$ is an upper bound of $A \cup B$.

Now we show that $\max\{\sup A, \sup B\}$ is the least upper bound of $A \cup B$. Let M be any upper bound of $A \cup B$. Then $z \leq M$ for any $z \in A \cup B$. In particular, $z \leq M$ for $z \in A \subseteq A \cup B$ and so M is an upper bound of A . It follows that $\sup A \leq M$. Similarly, we have $\sup B \leq M$. Thus $\max\{\sup A, \sup B\} \leq M$ and so $\max\{\sup A, \sup B\} = \sup A \cup B$. \square

Question 3 (ii). No, it is not true. An counter-example is as follows. Let $A = \{1, 2\}$ and let $B = \{1, 3\}$. Then $\sup A = \max A = 2$ and $\sup B = \max B = 3$. It follows that $\min\{\sup A, \sup B\} = \min\{2, 3\} = 2$. But $\sup A \cap B = \sup\{1\} = 1 \neq \min\{\sup A, \sup B\}$. \square

Question 5. First we show that $0 \leq x_n \leq 1$ by induction on n . When $n = 1$, we have $0 \leq x_1 = \frac{3}{4} \leq 1$. Suppose that $0 \leq x_{n-1} \leq 1$ with $n \geq 2$. Observe that

$$x_n = 2x_{n-1} - x_{n-1}^2 = 1 - (1 - 2x_{n-1} + x_{n-1}^2) = 1 - (1 - x_{n-1})^2.$$

Since $0 \leq 1 - x_{n-1} \leq 1$ by induction, we have $0 \leq x_n \leq 1$. The induction is finished and so $0 \leq x_n \leq 1$ for all n .

Observe that

$$x_{n+1} - x_n = (2x_n - x_n^2) - x_n = x_n - x_n^2 = x_n(1 - x_n).$$

Since $0 \leq x_n \leq 1$, we have $x_{n+1} - x_n = x_n(1 - x_n) \geq 0$ and so the sequence $\{x_n\}$ is monotone increasing and bounded. Thus the limit of $\{x_n\}$ exists. Let $A = \lim_{n \rightarrow \infty} x_n$.

From the equation $x_{n+1} = 2x_n - x_n^2$, we have

$$A = \lim_{n \rightarrow \infty} x_{n+1} = 2 \lim_{n \rightarrow \infty} x_n - \left(\lim_{n \rightarrow \infty} x_n \right)^2 = 2A - A^2.$$

and so $A = 0$ or 1 . Since $x_n \geq x_1 = \frac{3}{4}$, we have $A = \lim_{n \rightarrow \infty} x_n \geq \frac{3}{4}$ and so $A \neq 0$. Thus $A = 1$. \square

Question 6. We already prove that $\overline{\lim}_{n \rightarrow \infty} a_n = \lim_{n \rightarrow \infty} a_n = A$. Now we show that $\underline{\lim}_{n \rightarrow \infty} a_n = \lim_{n \rightarrow \infty} a_n = A$. Let $c_n = \inf_{k \geq n} a_k$. Given any $\epsilon > 0$, there exists a positive integer N such that $|a_n - A| < \frac{\epsilon}{2}$ for $n > N$ and so $A - \frac{\epsilon}{2} < a_k < A + \frac{\epsilon}{2}$ for $k \geq n > N$. Thus $A - \frac{\epsilon}{2} \leq c_n = \inf_{k \geq n} a_k < A + \frac{\epsilon}{2}$ for $n > N$. It follows that $|c_n - A| \leq \frac{\epsilon}{2} < \epsilon$ for $n > N$ and so $\lim_{n \rightarrow \infty} a_n = \lim_{n \rightarrow \infty} c_n = A = \lim_{n \rightarrow \infty} a_n$. \square

Question 7 (a). Since $\{a_n\} = \{4 + \cos \frac{n\pi}{2}\} = \{4, 3, 4, 5, 4, 3, 4, 5, 4, 3, 4, 5, \dots\}$, we have

$$b_n = \sup\{a_n, a_{n+1}, a_{n+2}, \dots\} = 5 \quad \text{and} \quad c_n = \inf\{a_n, a_{n+1}, a_{n+2}, \dots\} = 3$$

for all n and so $\overline{\lim}_{n \rightarrow \infty} 4 + \cos \frac{n\pi}{2} = \lim_{n \rightarrow \infty} b_n = 5$ and $\underline{\lim}_{n \rightarrow \infty} 4 + \cos \frac{n\pi}{2} = \lim_{n \rightarrow \infty} c_n = 3$. \square

Question 7 (b). Observe that

$$0 \leq \frac{1 + (-1)^n}{n} \leq \frac{2}{n}.$$

Since $\lim_{n \rightarrow \infty} \frac{2}{n} = \lim_{n \rightarrow \infty} 0 = 0$, we have $\lim_{n \rightarrow \infty} \frac{1 + (-1)^n}{n} = 0$ and so

$$\overline{\lim}_{n \rightarrow \infty} \frac{1 + (-1)^n}{n} = \underline{\lim}_{n \rightarrow \infty} \frac{1 + (-1)^n}{n} = \lim_{n \rightarrow \infty} \frac{1 + (-1)^n}{n} = 0.$$

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