1 Porblems set 1(Real Numbers)

1. Prove the following statements are true in every ordered field.

   (a) If $x > 0$ then $-x < 0$, and vice versa.

   (b) If $x > 0$ and $y < z$ then $xy < xz$.

   (c) If $x < 0$ and $y < z$ then $xy > xz$.

   (d) If $x \neq 0$ then $x^2 > 0$. In particular, $1 > 0$.

   (e) If $0 < x < y$ then $0 < 1/y < 1/x$.

2. Let $S \subset \mathbb{R}$ and $a \in \mathbb{R}$. Prove that

   (a) $\sup(a + S) = a + \sup S$

   (b) If $a > 0$ then $\sup(aS) = a \sup S$

   (c) If $a > 0$ then $\sup(aS) = a \inf S$

3. Prove that supremum property implies infimum property.

4. Use Archimedean Property to prove the following

   (a) If $S := \{1/n : n \in \mathbb{N}\}$, then $\inf S = 0$.

   (b) If $t > 0$, there exists $n_t \in \mathbb{N}$ such that $0 < 1/n_t < t$.

   (c) If $y > 0$, there exists $n_y \in \mathbb{N}$ such that $n_y - 1 \leq y \leq n_y$.

   (d) If $S := \left\{\frac{1}{n} - \frac{1}{m} : n, m \in \mathbb{N}\right\}$, find $\inf S$ and $\sup S$.

5. Prove that between any two real numbers there is an irrational number.

6. Let $I_n := [0, 1/n]$ for $n \in \mathbb{N}$. Prove that

$$\bigcap_{n=1}^{\infty} I_n = \{0\}.$$

7. Let $J_n := (0, 1/n)$ for $n \in \mathbb{N}$. Prove that

$$\bigcap_{n=1}^{\infty} J_n = \emptyset.$$

8. Let $K_n := (n, \infty)$ for $n \in \mathbb{N}$. Prove that

$$\bigcap_{n=1}^{\infty} K_n = \emptyset.$$

2 Problem set 2(Sequences)

1. Find $K(\epsilon)$ for the following sequences
   (a) $\frac{1}{5n+1}$; $\epsilon = \frac{1}{6}$
   (b) $\frac{2}{n^3} + 5$; $\epsilon = \frac{1}{8}$
   (c) $\frac{3n}{2n+1}$; $\epsilon = \frac{1}{10}$
   (d) $\frac{n^2+n}{2n^2-1}$; $\epsilon = \frac{1}{5}$
   (e) $(-1)^n \frac{1}{n}$; $\epsilon = \frac{1}{61}$
2. Porve that limit of a sequence if it exist is unique.
3. Evaluate the following limits (also prove it using the definition of limit):
   (a) $\lim_{n\to\infty} \frac{3n}{2n+1}$
   (b) $\lim_{n\to\infty} \frac{n}{n^2+1}$
   (c) $\lim_{n\to\infty}(\sqrt{n+1} - \sqrt{n})$
4. Let x_n, y_n be two sequences such that $x_n \to x$ and $y_n \to y$. Prove that:
   (a) $x_n + y_n \to x + y$
   (b) $x_n - y_n \to x - y$
   (c) $x_n y_n \to xy$
   (d) $x_n/y_n \to x/y$ if $y \neq 0$
5. Prove that if $x_n \to x$ then $|x_n| \to |x|$ and $\sqrt{|x_n|} \to \sqrt{|x|}$.
6. Prove squeeze theroerm: If $x_n \leq y_n \leq z_n$ for all n and $x_n \to L$, $z_n \to L$, then $y_n \to L$.
7. Prove that for any real number x, there exists a sequence of rational numbers (x_n) such that $x_n \to x$.

3 Problem set 3(Sequences)

1. Is the sequence $log(n) - log(n+1)$ convergent?

2. Let x_n converges to x. Prove that any subsequence of x_n is convergent to x.

3. True or False : Let (a_n) be a sequence such that a_{nk} converges for $k \in \mathbb{N} - \{1\}$. Then a_{nk} converges.

4. Give an example of an unbounded sequence that has a convergent subsequence.

5. Suppose that $x_n \geq 0$ and $(-1)^n x_n$ convereges. Does it imply that x_n converges.

6. Let (x_n) be a bounded sequence and let $s := \sup\{x_n : n \in \mathbb{N}\}$. Show that if $s \notin \{x_n : n \in \mathbb{N}\}$, then there is a subsequence of (x_n) that converges to s.

7. Show directly that bounded monotone sequence is a cauchy sequence.

8. Let $Y = (y_n)$ be defined inductively by $y_1 := 1$, $y_{n+1} := \frac{1}{4}(2y_n + 3)$ for $n \geq 1$. Show that $\lim Y = 3/2$.

4 Problem set 4 (Limits and Continuity)

1. Let $f, g : \mathbb{R} \to \mathbb{R}$ be two functions continous at x_0. Prove that:
   (a) $f + g$ is continuous at x_0.
   (b) $f - g$ is continuous at x_0.
   (c) fg is continuous at x_0.
   (d) f/g is continuous at x_0 if $g(x_0) \neq 0$.
2. Prove that all polynomials from $\mathbb{R} \to \mathbb{R}$ are continuous functions. Are they uniformly continuous?
3. Let $f : \mathbb{R} \to \mathbb{R}$ be a continuous function such that $f(x) = 0$ for all $x \in \mathbb{Q}$. Prove that $f(x) = 0$ for all $x \in \mathbb{R}$.
4. Prove that composition of two continuous functions is continuous.
5. Prove that x^2 is uniformly continuous on $[0, 100]$
6. Prove that x^2 is not uniformly continuous on $\mathbb{R}$.
7. Prove that $\frac{1}{x}$ is not uniformly continuous on $(0, 1)$.