# 18.100A Assignment 6

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March 7, 2023

## Problem 1

### (a)

$$\begin{aligned}
\sum_{n=1}^{\infty} \frac{3}{9n+1} &= 3\sum_{n=1}^{\infty} \frac{1}{9n+1} && (1)\\
&= \frac{1}{3}\sum_{n=1}^{\infty} \frac{1}{n+\frac{1}{9}} && (2)\\
&= \frac{1}{3}\sum_{n=2}^{\infty} \frac{1}{(n-1)+\frac{1}{9}} && (3)\\
&= \frac{1}{3}\sum_{n=2}^{\infty} \frac{1}{n-\frac{8}{9}} && (4)\\
&> \sum_{n=2}^{\infty} \frac{1}{n}. && (5)
\end{aligned}$$

But the Harmonic series, $\sum_n \frac{1}{n}$, diverges.

Therefore, we conclude by comparison that the series $\sum_n \frac{3}{9n+1}$ diverges.

### (b)

$$\sum_{n=1}^{\infty} \frac{1}{2n-1} = \frac{1}{2}\sum_{n=1}^{\infty} \frac{1}{n-\frac{1}{2}} > \frac{1}{2}\sum_{n=1}^{\infty} \frac{1}{n}. \tag{6}$$

Therefore, by comparison, $\sum_n \frac{1}{2n-1}$ diverges.

### (c)

$$\sum_{n=1}^{\infty} \frac{(-1)^n}{n^2} = \sum_{k=1}^{\infty} \frac{1}{(2k)^2} - \sum_{k=1}^{\infty} \frac{1}{(2k+1)^2}, \tag{7}$$

which is the difference of two convergent series.

Therefore, $\sum_n \frac{(-1)^n}{n^2}$ converges.

### (d)

We can express the series $\sum_n \frac{1}{n(n+1)}$ as a telescoping sum:

$$\sum_{n=1}^{\infty} \frac{1}{n(n+1)} = \sum_{n=1}^{\infty} \frac{1}{n} - \sum_{n=1}^{\infty} \frac{1}{n+1} \tag{8}$$

$$= \left(1 - \frac{1}{2}\right) + \left(\frac{1}{2} - \frac{1}{3}\right) + \left(\frac{1}{3} - \frac{1}{4}\right) + \cdots \tag{9}$$

$$= 1. \tag{10}$$

Therefore, $\sum_n \frac{1}{n(n+1)}$ converges to 1.

### (e)

We note that $\forall n \in \mathbb{N}$, $e^{n^2} \geq n^3$. Then we have

$$\sum_{n=1}^{\infty} \frac{n}{e^{n^2}} \leq \sum_{n=1}^{\infty} \frac{n}{n^3} = \sum_{n=1}^{\infty} \frac{1}{n^2}, \tag{11}$$

which converges.

Therefore, $\sum_n ne^{-n^2}$ converges.

## Problem 2

### (a)

*Proof.* Suppose $\sum_n x_n$ converges.

Then the sequence of partial sums $\{s_m\}_m = \{x_1 + \cdots x_m\}_{m=1}^{\infty}$ also converges.

We construct two subsequences of $\{s_m\}_m$, defined via

$$\{s_{m_{2k}}\}_k = \{x_2, x_2 + x_4, x_2 + x_4 + x_6, \cdots\} = \{x_2 + \cdots x_{2k}\}_k, \tag{12}$$

and

$$\{s_{m_{2k+1}}\}_k = \{x_1, x_1 + x_3, x_1 + x_3 + x_7, \cdots\} = \{x_1 + \cdots x_{2k+1}\}_k. \tag{13}$$

Note that for each $m \in \mathbb{N}$, if $m$ is even then $m = 2k$ for some $k \in \mathbb{N}$. Then

$$s_m = s_{m_{2k-1}} + s_{m_{2k}}. \tag{14}$$

Likewise if $m$ is odd, then

$$s_m = s_{m_{2k}} + s_{m_{2k+1}}. \tag{15}$$

In both cases, the partial sum $s_m$ must converge because the series $\sum_n x_n$ converges. Thus, the sum of the two partial sums must also converge, i.e. $\{s_{m_{2k}}\}_k$ and $\{s_{m_{2k+1}}\}_k$ both converge.

Then both series $\sum_n x_{2n}$ and $\sum_n x_{2n+1}$ must converge, and so does their sum:

$$\sum_n x_{2n} + \sum_n x_{2n+1} < \infty. \tag{16}$$

Therefore, $\sum_n (x_{2n} + x_{2n+1})$ converges. $\square$

### (b)

Consider the following counterexample to the converse of the theorem proven in problem **(a)**:

Let $x_n = (-1)^n$. Then

$$\begin{aligned}
\sum_{n=1}^{\infty} (x_{2n} + x_{2n+1}) &= \sum_{n=1}^{\infty} \left[(-1)^{2n} + (-1)^{2n+1}\right] && (17)\\
&= \sum_{n=1}^{\infty} (1^n - 1^n) && (18)\\
&= 0. && (19)
\end{aligned}$$

But $\sum_n (-1)^n$ does not converge.

Therefore, the converse to **(a)** does not always hold.

## Problem 3

*Proof.* Suppose $\sum_n x_n$ converges absolutely.

Since the series $\sum_n |x_n|$ converges, then $\sum_n x_n$ converges by comparison, because $x_n \le |x_n|$.

Let $N \in \mathbb{N}$. Then the triangle inequality gives

$$|x_1 + x_2 + \cdots + x_N| \le |x_1| + |x_2| + \cdots + |x_N| = \sum_{n=1}^{N} |x_n|. \tag{20}$$

Because $\sum_n |x_n|$ converges, we can now take $N \to \infty$, which gives

$$\left|\sum_{n=1}^{\infty} x_n\right| \le \sum_{n=1}^{\infty} |x_n|, \tag{21}$$

as desired. $\square$

# Problem 4

## (a)

Using the sum of a geometric series, we have

$$\begin{align}
\sum_{n=1}^{\infty} \frac{1}{2^{2n+1}} &= \frac{1}{2} \sum_{n=1}^{\infty} \frac{1}{2^{2n}} \tag{22} \\
&= \frac{1}{2} \sum_{n=1}^{\infty} \left(\frac{1}{4}\right)^n \tag{23} \\
&= \frac{1}{2} \cdot \frac{1}{1 - \frac{1}{4}} \tag{24} \\
&= \frac{1}{2} \cdot \frac{4}{3}. \tag{25}
\end{align}$$

Therefore, $\sum_n \left(\frac{1}{2}\right)^{2n+1}$ converges to $\frac{2}{3}$.