Name: ______________________________

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TA: ______________________________

Answer Key

Math 10B: Practice Final

Print your name at the top of every page and write your PID in the space provided above.

Turn off and put away your cell phone.
No calculators or any other electronic devices are allowed during this exam.
You may use one page of notes, but no books or other assistance during this exam.
Read each question carefully, and answer each question completely.
Show all of your work; no credit will be given for unsupported answers.
Write your solutions clearly and legibly; no credit will be given for illegible solutions.
If any question is not clear, ask for clarification.
You have 3 hours.

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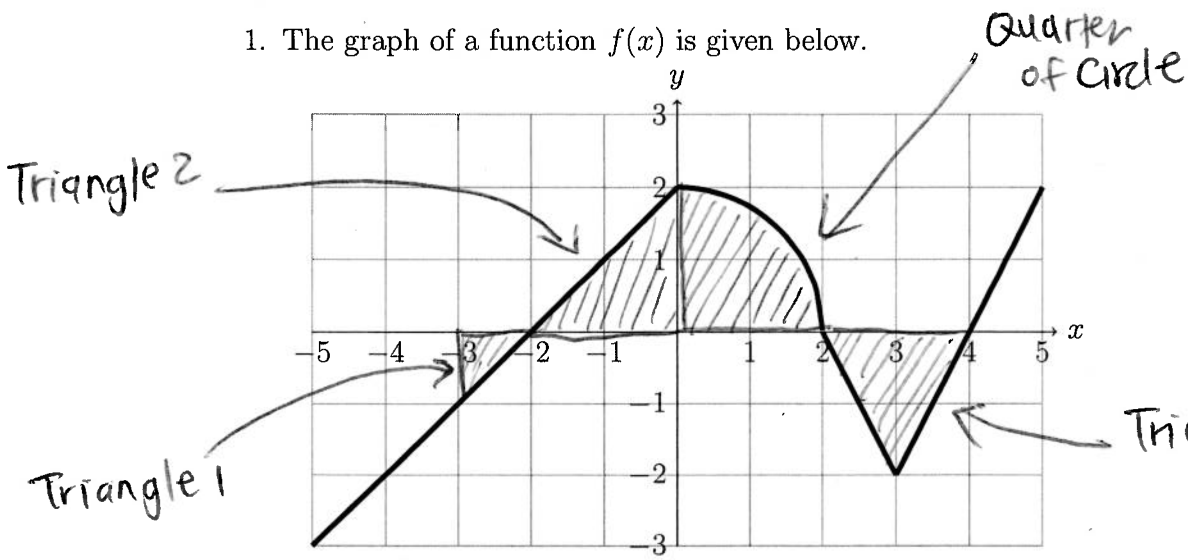
1. The graph of a function $f(x)$ is given below.



Use the graph to find $\int_{-3}^{4} f(x)\,dx$. *You may assume that curve from $x = 0$ to $x = 2$ is part of the circle $x^2 + y^2 = 4$.*

Area of Triangle 1 $= \frac{1}{2}bh = \frac{1}{2}(1)(1) = \frac{1}{2}$

Area of Triangle 2 $= \frac{1}{2}bh = \frac{1}{2}(2)(2) = 2$

Area of Quarter of Circle $= \frac{1}{4}\pi r^2 = \frac{1}{4}\pi(2^2) = \pi$

Area of Triangle 3 $= \frac{1}{2}bh = \frac{1}{2}(2)(2) = 2$

$\int_{-3}^{4} f(x)\,dx =$ areas above x-axis $-$ areas below x-axis

$= 2 + \pi - \frac{1}{2} - 2$

$= \boxed{\pi - \frac{1}{2}}$

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2. Evaluate each integral.

(a) $\int_{\frac{1}{5}}^{1} \frac{e^{\frac{1}{x}}}{x^2}\,dx$ $= -\int_5^1 e^u\,du$

$u = \frac{1}{x}$

$du = -\frac{1}{x^2}dx$

$-du = \frac{1}{x^2}dx$

$u(1) = \frac{1}{1} = 1$

$u(\frac{1}{5}) = \frac{1}{\frac{1}{5}} = 5$

$= \int_1^5 e^u\,du$

$= e^u \Big|_1^5$

$= \boxed{e^5 - e}$

(b) $\int x^3\sqrt{x^2+1}\,dx$ $= \int x^2\sqrt{x^2+1}\;x\,dx$

$u = x^2+1$

$du = 2x\,dx$

$\frac{1}{2}du = x\,dx$

$x^2 = u-1$

$= \frac{1}{2}\int (u-1)\sqrt{u}\,du$

$= \frac{1}{2}\int (u-1)u^{\frac{1}{2}}\,du$

$= \frac{1}{2}\int u^{\frac{3}{2}} - u^{\frac{1}{2}}\,du$

$= \frac{1}{2}\left(\frac{2}{5}u^{\frac{5}{2}} - \frac{2}{3}u^{\frac{3}{2}}\right) + C$

$= \frac{1}{2}\left(\frac{2}{5}(x^2+1)^{\frac{5}{2}} - \frac{2}{3}(x^2+1)^{\frac{3}{2}}\right) + C$

$= \boxed{\frac{1}{5}(x^2+1)^{\frac{5}{2}} - \frac{1}{3}(x^2+1)^{\frac{3}{2}} + C}$

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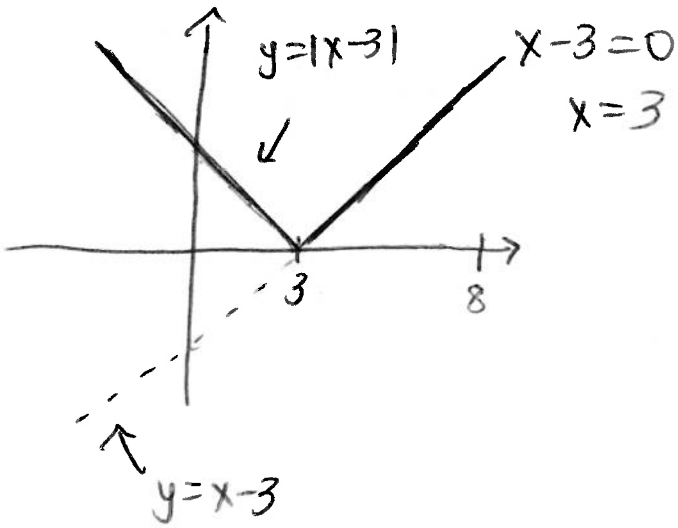
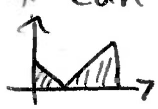
(c) $\int_0^8 |x-3|\,dx$



$$\int_0^8 |x-3|\,dx$$
$$= \int_0^3 |x-3|\,dx + \int_3^8 |x-3|\,dx$$
$$= -\int_0^3 x-3\,dx + \int_3^8 x-3\,dx$$
$$= -\left(\tfrac{1}{2}x^2-3x\right)\Big|_0^3 + \left(\tfrac{1}{2}x^2-3x\right)\Big|_3^8$$
$$= -\left[\left(\tfrac{9}{2}-9\right)-0\right]$$
$$+\left[(32-24)-\left(\tfrac{9}{2}-9\right)\right]$$
$$= \tfrac{9}{2}+8+\tfrac{9}{2} = \boxed{17}$$

* can also find using areas:



$\frac{1}{2}(3)(3)+\frac{1}{2}(5)(5)=17$

(d) $\int x^{-2}\arctan x\,dx$

$u=\arctan x \qquad dv = x^{-2}\,dx$

$du = \frac{1}{1+x^2}\,dx \qquad v = -\frac{1}{x}$

$$= -\frac{1}{x}\arctan x + \int \frac{1}{x(1+x^2)}\,dx$$

$$\frac{1}{x(1+x^2)} = \frac{A}{x} + \frac{Bx+C}{x^2+1} = \frac{A(x^2+1)+(Bx+C)x}{x(x^2+1)}$$

$$\left.\begin{aligned} Ax^2+A+Bx^2+Cx&=1\\ (A+B)x^2+Cx+A&=1\end{aligned}\right\}\quad \left.\begin{aligned} A+B&=0\\ C&=0\\ A&=1\end{aligned}\right\}\quad B=-1$$

$$\int \frac{1}{x(x^2+1)}\,dx = \int \frac{1}{x} - \frac{x}{x^2+1}\,dx = \ln|x| - \int \frac{x}{x^2+1}\,dx$$

$u=x^2+1$

$du = 2x\,dx$

$\frac{1}{2}du = x\,dx$

$$= \ln|x| - \frac{1}{2}\int \frac{1}{u}\,du$$
$$= \ln|x| - \frac{1}{2}\ln|u| + C$$
$$= \ln|x| - \frac{1}{2}\ln(x^2+1) + C$$

$$= \boxed{-\frac{1}{x}\arctan x + \ln|x| - \frac{1}{2}\ln(x^2+1) + C}$$

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(e) $\int \sin^5 x \, dx$

$= \int \sin^4 x \sin x \, dx$

$= \int (\sin^2 x)^2 \sin x \, dx$

$= \int (1-\cos^2 x)^2 \sin x \, dx$

$u = \cos x$

$du = -\sin x \, dx$

$-du = \sin x \, dx$

$= -\int (1-u^2)^2 \, du$

$= -\int u^4 - 2u^2 + 1 \, du$

$= -\left(\frac{1}{5}u^5 - \frac{2}{3}u^3 + u\right) + C$

$= \boxed{-\frac{1}{5}\cos^5 x + \frac{2}{3}\cos^3 x - \cos x + C}$

(f) $\int \frac{\sqrt{x^2-16}}{x^4} \, dx$ $= \int \frac{\sqrt{16\sec^2\theta - 16}}{4^4 \sec^4\theta} 4\sec\theta\tan\theta \, d\theta$

$x = 4\sec\theta$

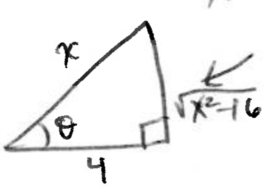
$dx = 4\sec\theta\tan\theta \, d\theta$

$= \int \frac{4\sqrt{\sec^2\theta - 1}}{4^3\sec^3\theta} \tan\theta \, d\theta$

$\sec\theta = \frac{x}{4}$

$\cos\theta = \frac{4}{x}$

$= \int \frac{\sqrt{\tan^2\theta}}{16\sec^3\theta} \tan\theta \, d\theta$



$4^2 + b^2 = x^2$

$b = \sqrt{x^2-16}$

$= \frac{1}{16}\int \frac{\tan^2\theta}{\sec^3\theta} \, d\theta$

$* \tan\theta = \frac{\sin\theta}{\cos\theta}$

$* \sec\theta = \frac{1}{\cos\theta}$

$= \frac{1}{16}\int \frac{\sin^2\theta}{\cos^2\theta} \cdot \cos^3\theta \, d\theta$

$= \frac{1}{16}\int \sin^2\theta\cos\theta \, d\theta$

$u = \sin\theta$

$du = \cos\theta \, d\theta$

$= \frac{1}{16}\int u^2 \, du = \frac{1}{16}\left(\frac{1}{3}u^3\right) + C = \frac{1}{48}\sin^3\theta + C$

$= \boxed{\frac{1}{48}\left(\frac{\sqrt{x^2-16}}{x}\right)^3 + C}$

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3. Let $g(x) = \int_0^x \sin t \, dt$ for $0 \le x \le 2\pi$.

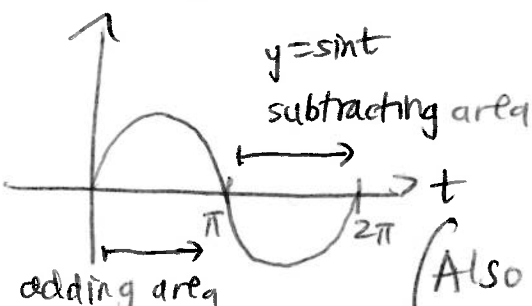
(a) Find $g\left(\frac{\pi}{2}\right)$.

$$g\left(\tfrac{\pi}{2}\right) = \int_0^{\frac{\pi}{2}} \sin t \, dt = -\cos t \Big|_0^{\frac{\pi}{2}} = -(0-1) = \boxed{1}$$

(b) Find $g'(x)$.

$$\boxed{g'(x) = \sin x}$$

(c) On what interval of x is $g(x)$ increasing? On what interval of x is $g(x)$ decreasing?



$\boxed{\begin{array}{l} g \text{ is increasing on } (0,\pi) \\ \& \text{ decreasing on } (\pi, 2\pi) \end{array}}$

(Also: $g'(x) = \sin x > 0$ for x in $(0,\pi)$, $\sin x < 0$ for x in $(\pi, 2\pi)$)

(d) Find the maximum value of $g(x)$ on $[0, 2\pi]$. Find the minimum value of $g(x)$ on $[0, 2\pi]$.

The graph shows us that the max. value of $g(x)$ is $g(\pi) = \int_0^{\pi} \sin t \, dt = -\cos t \Big|_0^{\pi}$

$= -(-1-1) = \boxed{2}$

& the min. value is $g(0) = \int_0^0 \sin t \, dt = \boxed{0}$

(or $g(2\pi)$)

(Also: Closed Interval Method for Abs. Max/Min:

critical pt $x = \pi \Rightarrow g(\pi) = 2 \to \max$

end pt $x = 0 \Rightarrow g(0) = 0 \to \min$.

end pt $x = 2\pi \Rightarrow g(2\pi) = 0$)

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4. Determine whether each integral is convergent or divergent.

(a) $\displaystyle\int_0^\infty \frac{e^x}{1+e^{2x}}\,dx$

$$= \lim_{t\to\infty} \int_0^t \frac{e^x}{1+e^{2x}}\,dx$$

$$= \lim_{t\to\infty} \int_1^{e^t} \frac{1}{1+u^2}\,du$$

$u = e^x$
$du = e^x dx$
$u(0) = e^0 = 1$
$u(t) = e^t$

$$= \lim_{t\to\infty} \arctan u \Big|_1^{e^t}$$

$$= \lim_{t\to\infty} \left(\arctan(e^t) - \arctan 1\right)$$

$$= \frac{\pi}{2} - \frac{\pi}{4} = \boxed{\frac{\pi}{4}} \Rightarrow \boxed{\text{convergent}}$$

(b) $\displaystyle\int_1^\infty \frac{x^2}{x^3-1}\,dx$ *Hint: Use the comparison theorem.*

For $x \geq 1$, $x^3 - 1 < x^3$

$$\frac{1}{x^3-1} > \frac{1}{x^3}$$

$$\frac{x^2}{x^3-1} > \frac{x^2}{x^3}$$

$$\frac{x^2}{x^3-1} > \frac{1}{x}.$$

Since $\int_1^\infty \frac{1}{x}\,dx$ is divergent ($p = 1 \leq 1$), by the comparison thm. $\int_1^\infty \frac{x^2}{x^3-1}\,dx$ is also $\boxed{\text{divergent}}$

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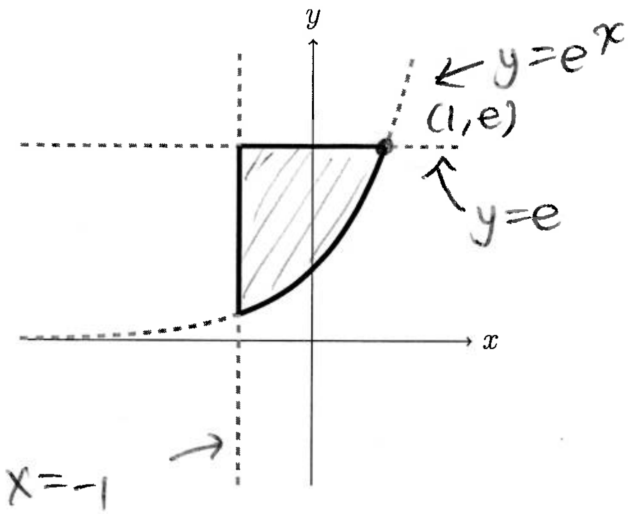
5. Find the areas of the region(s) enclosed by the given curves.

(a) $y = e^x$, $y = e$, $x = -1$



$e^x = e$

$x = 1$

$$\text{Area} = \int_a^b \text{top function} - \text{bottom function}\, dx$$

$$= \int_{-1}^{1} e - e^x \, dx$$

$$= (ex - e^x)\Big|_{-1}^{1}$$

$$= (e - e) - (-e - e^{-1})$$

$$= \boxed{e + \frac{1}{e}}$$

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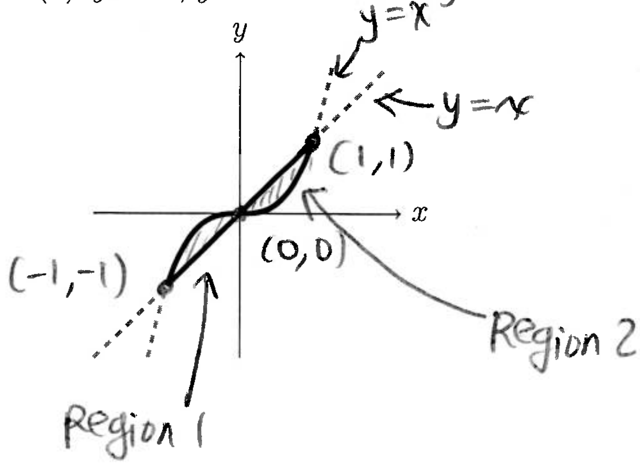
(b) $y = x^3$, $y = x$



$$x^3 = x$$
$$x^3 - x = 0$$
$$x(x^2-1) = 0$$
$$x = 0, \pm 1$$

$$\text{Total area} = \text{area of Region 1} + \text{area of Region 2}$$
$$= \int_{-1}^{0} x^3 - x \, dx + \int_0^1 x - x^3 \, dx$$
$$= \left(\frac{1}{4}x^4 - \frac{1}{2}x^2\right)\Big|_{-1}^{0} + \left(\frac{1}{2}x^2 - \frac{1}{4}x^4\right)\Big|_0^1$$
$$= \left(0 - \left(\frac{1}{4} - \frac{1}{2}\right)\right) + \left(\left(\frac{1}{2} - \frac{1}{4}\right) - 0\right)$$
$$= \frac{1}{4} + \frac{1}{4} = \boxed{\frac{1}{2}}$$

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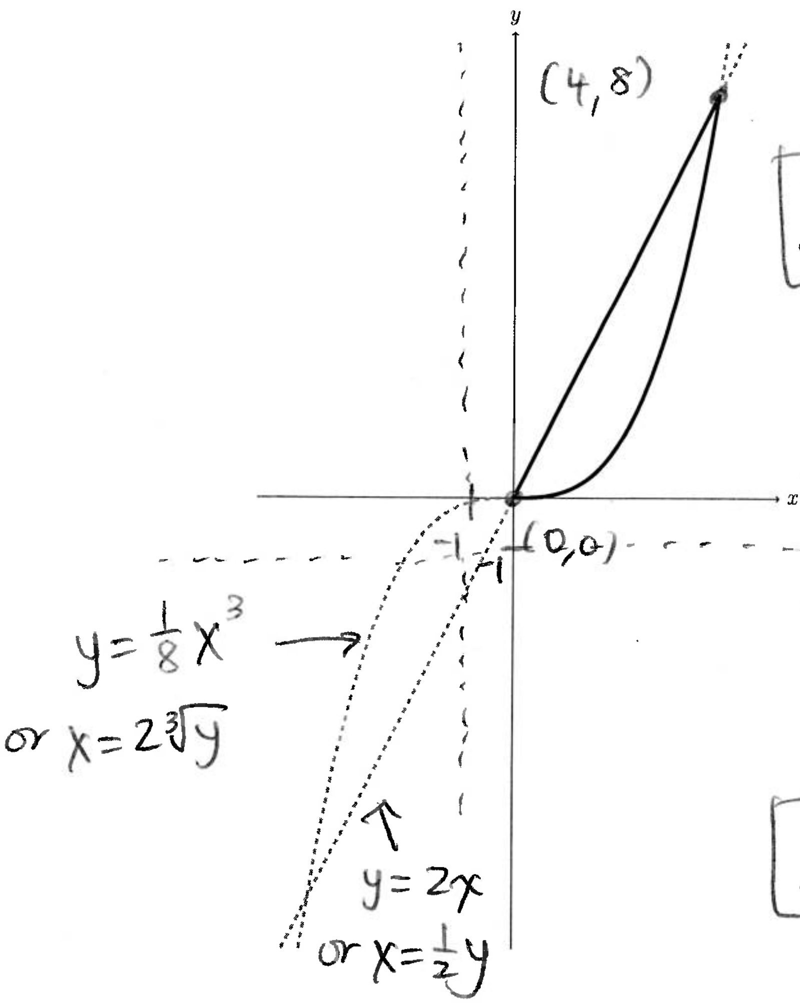
6. Set up, **but do not evaluate**, an integral for the volume of the solid of revolution obtained by revolving the region in the first quadrant bounded by $y = \frac{1}{8}x^3$ and $y = 2x$ about each of the following lines:



(a) x-axis

Δx

$r_{out} = 2x - 0$

$r_{in} = \frac{1}{8}x^3 - 0$

$$\boxed{\int_0^4 \pi(2x-0)^2 - \pi\left(\tfrac{1}{8}x^3-0\right)^2 dx}$$

(b) y-axis

Δy

$r_{out} = 2\sqrt[3]{y} - 0$

$r_{in} = \frac{1}{2}y - 0$

$$\boxed{\int_0^8 \pi\left(2\sqrt[3]{y}-0\right)^2 - \pi\left(\tfrac{1}{2}y-0\right)^2 dy}$$

(c) $y = -1$

Δx

$r_{out} = 2x - (-1)$

$r_{in} = \frac{1}{8}x^3 - (-1)$

$$\boxed{\int_0^4 \pi(2x-(-1))^2 - \pi\left(\tfrac{1}{8}x^3-(-1)\right)^2 dx}$$

(d) $x = -1$

Δy

$r_{out} = 2\sqrt[3]{y} - (-1)$

$r_{in} = \frac{1}{2}y - (-1)$

$$\boxed{\int_0^8 \pi\left(2\sqrt[3]{y}-(-1)\right)^2 - \pi\left(\tfrac{1}{2}y-(-1)\right)^2 dy}$$

$\frac{1}{8}x^3 = 2x$

$x^3 = 16x$

$x^3 - 16x = 0$

$x(x^2-16) = 0$

$x = 0, \pm 4$

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If $x \neq 0, \frac{\pi}{2}, \frac{3\pi}{2}, \pi, \ldots -\frac{\pi}{2}, -\frac{3\pi}{2}, -\pi, k$.

7. Find the values of x for which $\sum_{n=0}^{\infty} \frac{\sin^n(2x)}{3^n}$ converges.

$$\sum_{n=0}^{\infty}\left[\frac{\sin(2x)}{3}\right]^n = 1 + \frac{\sin 2x}{3} + \left(\frac{\sin 2x}{3}\right)^2 + \left(\frac{\sin 2x}{3}\right)^3$$

This is a geometric series, $a=1$, $r = \frac{\sin 2x}{3}$

Since $\left|\frac{\sin 2x}{3}\right| \leq \frac{1}{3} < 1 \Rightarrow \sum_{n=0}^{\infty}\left[\frac{\sin(2x)}{3}\right]^n$ converges

for all $x \neq 0, \frac{\pi}{2}, \frac{3\pi}{2} \ldots -\pi, -\frac{\pi}{2}, -\frac{3\pi}{2} \ldots$

If $x = 0, \frac{\pi}{2}, \frac{3\pi}{2}, \pi \ldots, -\frac{\pi}{2}, -\frac{3\pi}{2}, -\pi$ $\sum_{n=0}^{\infty}\left(\frac{\sin 2x}{3}\right)^n = \sum_{n=0}^{\infty} 0 = 0$

which converges to 0.

So $\sum_{n=0}^{\infty} \frac{\sin^n(2x)}{3^n}$ converges for all x.

8. Determine whether the sequence converges or diverges. If it converges, find the limit.

(a) $a_n = \dfrac{n^5}{2-n}$

note: $\dfrac{n^5}{2-n} = \dfrac{n^5 \cdot \frac{1}{n}}{(2-n)\frac{1}{n}} = \dfrac{n^4}{\frac{2}{n} - 1}$

So: $\lim_{n\to\infty} \dfrac{n^5}{2-n} = \lim_{n\to\infty} \dfrac{n^4}{\frac{2}{n}-1} = -\infty$

$\boxed{\text{The sequence diverges.}}$

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(b) $a_n = 10\sin\left(\frac{5}{n}\right)$

$$\lim_{n\to\infty} 10\sin\left(\frac{5}{n}\right) = 10\lim_{n\to\infty} \sin\left(\frac{5}{n}\right) = 10\cdot\sin 0 = \boxed{0}$$

$\boxed{\text{Converges}}$

(c) $a_n = \dfrac{\cos(4n)}{2-n}$

$$\lim_{n\to\infty}\left|\frac{\cos(4n)}{2-n}\right| \leq \lim_{n\to\infty}\frac{1}{2-n} = 0$$

Because $\lim_{n\to\infty}\left|\frac{\cos(4n)}{2-n}\right| = 0$ then $\lim_{n\to\infty}\frac{\cos(4n)}{2-n} = \boxed{0}$

$\boxed{\text{Converges}}$

(d) $a_n = \left(4^{5n+\pi}\right)^{\frac{1}{n}}$

$$\lim_{n\to\infty}\left(4^{5n+\pi}\right)^{\frac{1}{n}} = \lim_{n\to\infty} 4^{\frac{5\cdot \cancel{n}}{\cancel{n}} + \frac{\pi}{n}} = \lim_{n\to\infty} 4^5\cdot 4^{\frac{\pi}{n}}$$

$$= 4^5\lim_{n\to\infty} 4^{\frac{\pi}{n}} = 4^5\cdot 1 = \boxed{1024}$$

$\boxed{\text{Converges}}$

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9. The half life of Cesium-137 is 30 years. Assume the quantity of Cesium-137 is described by the exponential model.

   (a) Find k. $P(t) = Ae^{kt}$

   Quantity of Cesium @ time t

   $A = P(0)$ = initial quantity of Cesium.

   @ $t = 30$ years: $\frac{1}{2}A = A e^{k \cdot 30} \Rightarrow \frac{1}{2} = e^{k \cdot 30}$

   $\ln\frac{1}{2} = \ln e^{k \cdot 30}$

   $\ln\frac{1}{2} = k \cdot 30$

   So: $\boxed{k = \frac{\ln\frac{1}{2}}{30}}$

   (b) If the initial quantity is 10mg, find the equation describing the mass remaining after 90 years. (Leave your answer unsimplified).

   $P(t) = 10e^{t\frac{\ln\frac{1}{2}}{30}} \Rightarrow P(90\text{yrs.}) = \boxed{10e^{\frac{90\ln\frac{1}{2}}{30}}}$

   (c) How long will it take the sample to decay to 15% of its original quantity?

   15% of original quantity $= .15 \cdot 10\text{mg} = 1.5\text{mg}$

   Solve for t!

   $1.5\text{mg} = 10\text{mg}\, e^{t\frac{\ln\frac{1}{2}}{30}}$

   $.15 = e^{t\frac{\ln\frac{1}{2}}{30}}$

   $\ln .15 = \ln e^{t\frac{\ln\frac{1}{2}}{30}}$

   $\ln .15 = t\frac{\ln\frac{1}{2}}{30}$

   So: $\boxed{t = \frac{30\ln .15}{\ln\frac{1}{2}}}$

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10. The half life of caffeine is approximately 6 hours. One cup of coffee contains 95 mg of caffeine. If you drink one cup of coffee at 9am, how much caffeine is still in your body at 9pm?

$$y(t) = Ae^{kt}$$

Quantity of Caffeine in your body as a function of t

Initial Quantity of Caffeine $y(0) = A$.

Step 1: Find k using half life

$$A = 95\text{mg}, \quad y(t) = 95\text{mg}\, e^{kt}$$

$$y(6\text{hr}) = \frac{1}{2} \cdot \cancel{95\text{mg}} = \cancel{95\text{mg}}\, e^{k \cdot 6}$$

$$\frac{1}{2} = e^{k6}$$

$$\ln\frac{1}{2} = \ln e^{k6}$$

$$\text{So: } k = \frac{\ln\frac{1}{2}}{6}$$

Step 2: Find caffeine after 12hrs.

$$y(12\text{ hrs}) = 95e^{12\frac{\ln\frac{1}{2}}{6}} = \boxed{95e^{2\ln\frac{1}{2}}}$$

ie 9pm

note: $95e^{\ln(\frac{1}{2})^2} = 95e^{\ln\frac{1}{4}} = 95 \cdot \frac{1}{4}$

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11. In the early part of the 20th century, seals were actively hunted under a government program that viewed them as harmful predators which greatly reduced their numbers. Subsequently, seal populations have rebounded in a roughly logistic manner. In 1975, there were 1500 seals in Washington state. The carrying capacity for this population is aroud 7500. Assume the number of seals tripled in the first year.

(a) Assuming the size of the seal population satisfies the logistic equation, find an expression for the size of the population as a function of t where $t = 0$ corresponds to 1975.

$$P(t) = \frac{M}{1+Ae^{-kt}}, \quad A = \frac{M-P_0}{P_0}$$

$$A = \frac{75\cancel{00} - 15\cancel{00}}{15\cancel{00}} = \frac{60}{15} = 4$$

$$P(t) = \frac{7500}{1+4e^{-kt}}$$

$$4500 = \frac{7500}{1+4e^{-k}}$$

$$1+4e^{-k} = \frac{75\cancel{00}}{45\cancel{00}}$$

$$1+4e^{-k} = \frac{5}{3}$$

$$4e^{-k} = \frac{2}{3}$$

$$e^{-k} = \frac{1}{6}$$

$$-k = \ln\frac{1}{6}$$

$$k = -\ln\frac{1}{6} = \ln 6$$

$$\boxed{P(t) = \frac{7500}{1+4e^{-(\ln 6)t}} \text{ or } \frac{7500}{1+4\left(\frac{1}{6}\right)^t}}$$

(b) How long will it take the population to increase to 80% of the carrying capacity?

$$0.8(7500) = \frac{7500}{1+4e^{-kt}}$$

$$0.8 = \frac{1}{1+4e^{-kt}}$$

$$1+4e^{-kt} = \frac{5}{4}$$

$$4e^{-kt} = \frac{1}{4}$$

$$e^{-kt} = \frac{1}{16}$$

$$-kt = \ln\frac{1}{16}$$

$$t = \frac{-\ln\frac{1}{16}}{k} = \boxed{\frac{\ln 16}{\ln 6} \text{ yrs.}}$$

$$\approx 1.55 \text{ yrs}$$

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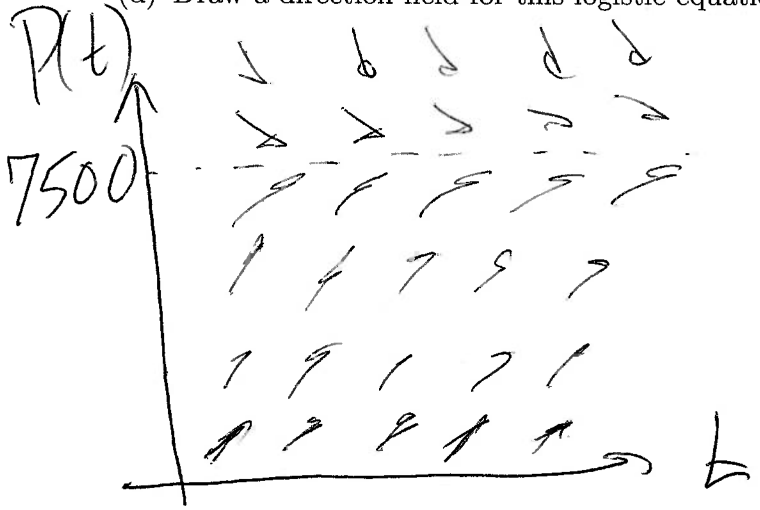
(c) What number of seals are expected to be in Washington state after many years?

Carrying Capacity = 7500

(d) Draw a direction field for this logistic equation.



note: $\frac{dP}{dt}$ is constant parallel to the t axis.

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12. Determine whether the series is convergent or divergent. If it is convergent, find its sum.

(a) $\sum_{n=1}^{\infty} \frac{n^2+2}{n^2-1}$ Consider $\lim_{n\to\infty} \frac{n^2+2}{n^2-1} = \lim_{n\to\infty} \frac{n^2+2}{n^2-1} \cdot \frac{\frac{1}{n^2}}{\frac{1}{n^2}}$

$= \lim_{n\to\infty} \frac{1+\frac{2}{n}}{1-\frac{1}{n}} = 1$

By Divergence test, since $\lim_{n\to\infty} \frac{n^2+2}{n^2-1} \neq 0$, series diverges

(b) $\sum_{n=1}^{\infty} \left(\sin\left(\frac{\pi}{4}\right)\right)^n$ Recall: $\sin\frac{\pi}{4} = \frac{\sqrt{2}}{2}$

$\sum_{n=1}^{\infty}\left(\frac{\sqrt{2}}{2}\right)^n = \frac{\sqrt{2}}{2} + \left(\frac{\sqrt{2}}{2}\right)^2 + \left(\frac{\sqrt{2}}{2}\right)^3 + \dots = \frac{\sqrt{2}}{2}\left(1 + \frac{\sqrt{2}}{2} + \left(\frac{\sqrt{2}}{2}\right)^2 + \dots\right)$

$a = \frac{\sqrt{2}}{2}$, $r = \frac{\sqrt{2}}{2}$. Since $|r|<1$, the geometric series converges to $\frac{\frac{\sqrt{2}}{2}}{1-\frac{\sqrt{2}}{2}} = \boxed{\frac{\sqrt{2}}{2-\sqrt{2}}}$

13. Solve the differential equation $y' = \frac{y}{x}$.

$y' = \frac{y}{x} \Rightarrow \frac{dy}{y} = \frac{dx}{x} \Rightarrow \ln|y| = \ln|x| + C$

$e^{\ln|y|} = e^{\ln|x| + C} = e^{\ln|x|} \cdot e^C$

$|y| = |x| \cdot e^C$

So: $y = \pm e^C x$ which we can write $\boxed{y = Ax \text{ for all } A \neq 0}$

Check for equlibrium/constant solutions

$y' = 0$ for $\boxed{y=0}$

So: The two solutions can be combined in 1 formula

$\boxed{y = Ax}$ for all A