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MATH 221 Exam 2 Version A Fall 2019

Section 504 Solutions P. Yasskin

1-9	/54	11	/20
10	/ 5	12	/25
		Total	/104

Multiple Choice: (6 points each. No part credit.)

1. Find the equation of the plane tangent to $z = x^2y^2 + xy^2$ at the point $(x,y) = (1,2)$.
Its z-intercept is:

a. $c = 20$

b. $c = 8$

c. $c = -8$

d. $c = -16$

e. $c = -20$ Correct Choice

Solution: $f(x,y) = x^2y^2 + xy^2$ $f_x(x,y) = 2xy^2 + y^2$ $f_y(x,y) = 2x^2y + 2xy$

$f(1,2) = 1^2 \cdot 2^2 + 1 \cdot 2^2 = 8$ $f_x(1,2) = 2 \cdot 1 \cdot 2^2 + 2^2 = 12$ $f_y(1,2) = 2 \bullet 1^2 \bullet 2 + 2 \cdot 1 \cdot 2 = 8$

Tangent plane: $z = f(1,2) + f_x(1,2)(x-1) + f_y(1,2)(y-2) = 8 + 12(x-1) + 8(y-2)$

$z = 12x + 8y - 20$ z-intercept is $c = -20$.

2. Use differentials to estimate the volume of metal needed to make a cylindrical tin can with lids if the radius is $r = 5$ cm and the height is $h = 6$ cm and the metal has thickness $.02$ cm?

a. 200π

b. 4π

c. 105π

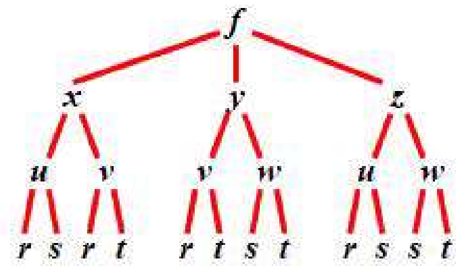
d. 2.2π Correct Choice

e. 2.6π

Solution: $V = \pi r^2 h$ $\Delta V \approx dV = \frac{\partial V}{\partial r}dr + \frac{\partial V}{\partial h}dh = 2\pi rh\,dr + \pi r^2\,dh$

$r = 5$ $h = 6$ $dr = .02$ $dh = .04$ $\Delta V \approx 2\pi(5)(6)(.02) + \pi(5)^2(.04) = 2.2\pi$

3. At the right is a tree diagram showing f as a function of x, y and z which are functions of u, v and w which are functions of r, s and t as indicated. Below are values of a bunch partial derivatives. Use this information to compute $\frac{\partial f}{\partial s}$.



$$\frac{\partial f}{\partial x} = 2 \qquad \frac{\partial f}{\partial y} = 3 \qquad \frac{\partial f}{\partial z} = 4$$

$$\frac{\partial x}{\partial u} = 5 \qquad \frac{\partial x}{\partial v} = 6 \qquad \frac{\partial y}{\partial v} = 7 \qquad \frac{\partial y}{\partial w} = 8 \qquad \frac{\partial z}{\partial u} = 9 \qquad \frac{\partial z}{\partial w} = 10$$

$$\frac{\partial u}{\partial r} = 6 \qquad \frac{\partial u}{\partial s} = 5 \qquad \frac{\partial v}{\partial r} = 4 \qquad \frac{\partial v}{\partial t} = 3 \qquad \frac{\partial w}{\partial s} = 2 \qquad \frac{\partial w}{\partial t} = 1$$

a. 163

b. 212

c. 358 Correct Choice

d. 396

e. 408

Solution
$$\frac{\partial f}{\partial s} = \frac{\partial f}{\partial x}\frac{\partial x}{\partial u}\frac{\partial u}{\partial s} + \frac{\partial f}{\partial y}\frac{\partial y}{\partial w}\frac{\partial w}{\partial s} + \frac{\partial f}{\partial z}\frac{\partial z}{\partial u}\frac{\partial u}{\partial s} + \frac{\partial f}{\partial z}\frac{\partial z}{\partial w}\frac{\partial w}{\partial s}$$
$$= 2 \cdot 5 \cdot 5 + 3 \cdot 8 \cdot 2 + 4 \cdot 9 \cdot 5 + 4 \cdot 10 \cdot 2 = 358$$

4. The point $(x,y) = (1,2)$ is a critical point of the function $f = 8x^3 + y^3 - 12xy$. Use the 2^{nd} Derivative Test to classify it as:

a. Local Minimum Correct Choice

b. Local Maximum

c. Inflection Point

d. Saddle Point

e. The 2^{nd} Derivative Test FAILS.

Solution: $f_x = 24x^2 - 12y \qquad f_y = 3y^2 - 12x \qquad f_x(1,2) = 24 - 12 \cdot 2 = 0 \qquad f_y(1,2) = 3 \cdot 4 - 12 = 0$

$f_{xx} = 48x \qquad f_{xx}(1,2) = 48 \qquad f_{yy} = 6y \qquad f_{yy}(1,2) = 12 \qquad f_{xy} = -12$

$D = f_{xx}f_{yy} - f_{xy}^2 = 48 \cdot 12 - 12^2 = 432$

$D > 0$ and $f_{xx} > 0$. So this is a local minimum.

5. If x, y and z are related by $x\cos y + z\sin y = 3$. Find $\frac{\partial z}{\partial x}$ at the point $(x,y,z) = \left(3, \frac{\pi}{3}, \sqrt{3}\right)$.

a. $\frac{1}{\sqrt{3}}$

b. $\frac{-1}{\sqrt{3}}$ Correct Choice

c. $\sqrt{3}$

d. $-\sqrt{3}$

e. $\frac{1}{3}$

Solution: Apply $\frac{\partial}{\partial x}$: $\cos y + \frac{\partial z}{\partial x}\sin y = 0$ $\frac{1}{2} + \frac{\partial z}{\partial x}\frac{\sqrt{3}}{2} = 0$ $\frac{\partial z}{\partial x} = \frac{-1}{\sqrt{3}}$

6. If x, y and z are related by $x\cos y + z\sin y = 3$. Find $\frac{\partial z}{\partial t}$ at the instant when:

$$(x,y,z) = \left(3, \frac{\pi}{3}, \sqrt{3}\right) \qquad \frac{dx}{dt} = \sqrt{3} \qquad \frac{dy}{dt} = 1$$

a. 1 Correct Choice

b. 2

c. 3

d. $\sqrt{3}$

e. $\frac{1}{\sqrt{3}}$

Solution: Apply $\frac{d}{dt}$: $\frac{dx}{dt}\cos y - x\sin y\frac{dy}{dt} + \frac{\partial z}{\partial t}\sin y + z\cos y\frac{dy}{dt} = 0$

Plug in numbers: $\sqrt{3}\,\frac{1}{2} - 3\frac{\sqrt{3}}{2}1 + \frac{\partial z}{\partial t}\frac{\sqrt{3}}{2} + \sqrt{3}\,\frac{1}{2}1 = 0$

Multiply by $\frac{2}{\sqrt{3}}$: $1 - 3 + \frac{\partial z}{\partial t} + 1 = 0$ $\frac{\partial z}{\partial t} = 1$

7. Find the tangent plane to the graph of the equation $xy - zy = 4$ at the point $(x,y,z) = (3,2,1)$. Its z-intercept is:

a. $c = -8$

b. $c = -4$ Correct Choice

c. $c = 0$

d. $c = 4$

e. $c = 8$

Solution: Let $f = xy - zy$ and $P = (3,2,1)$. Then $\vec{\nabla} f = \langle y, x-z, -y\rangle$

$\vec{N} = \vec{\nabla} f\big|_P = \langle 2,2,-2\rangle$ $\vec{N}\cdot X = \vec{N}\cdot P$ $2x + 2y - 2z = 2\cdot 3 + 2\cdot 2 - 2\cdot 1 = 8$

The z-intercept is $c = \frac{8}{-2} = -4$.

8. Queen Lena is flying the Centurion Eagle through a deadly Sythion field whose density is $S = xyz \dfrac{\text{Sythions}}{\text{microlightyear}^3}$. The top speed of the Centurion Eagle is $14 \dfrac{\text{microlightyears}}{\text{lightyear}}$. If Lena is located at the point $(x,y,z) = (1,2,3)$, what should her velocity be to **decrease** the Sythion density as fast as possible?

a. $\langle 6,3,2 \rangle$

b. $\langle -84,-42,-28 \rangle$

c. $\langle -6,-3,-2 \rangle$

d. $\langle 12,6,4 \rangle$

e. $\langle -12,-6,-4 \rangle$ Correct Choice

Solution:

$\vec{\nabla} S = \langle yz,xz,xy \rangle \qquad \vec{\nabla} S\Big|_{(1,2,3)} = \langle 6,3,2 \rangle \qquad \left|\vec{\nabla} S\right| = \sqrt{36+9+4} = 7 \qquad \widehat{\nabla S} = \dfrac{\vec{\nabla} S}{\left|\vec{\nabla} S\right|} = \left\langle \frac{6}{7}, \frac{3}{7}, \frac{2}{7} \right\rangle$

The direction of maximum decrease is $\vec{v} = -\widehat{\nabla S} = \left\langle \frac{-6}{7}, \frac{-3}{7}, \frac{-2}{7} \right\rangle$. The maximum speed is $|\vec{v}| = 14$.
So the velocity of maximum decrease is $\vec{v} = |\vec{v}|\hat{v} = 14\left\langle \frac{-6}{7}, \frac{-3}{7}, \frac{-2}{7} \right\rangle = \langle -12,-6,-4 \rangle$.

9. Consider the limit: $\displaystyle\lim_{(x,y)\to(0,0)} \frac{x^2y^2}{x^3+y^6}$. Which of the following directions of approach gives a different value of the limit?

a. Non-vertical line: $y = mx$ and $x \to 0$

b. The y-axis: $x = 0$ and $y \to 0$

c. The parabola: $x = y^2$ and $y \to 0$ Correct Choice

d. The parabola: $y = x^2$ and $x \to 0$

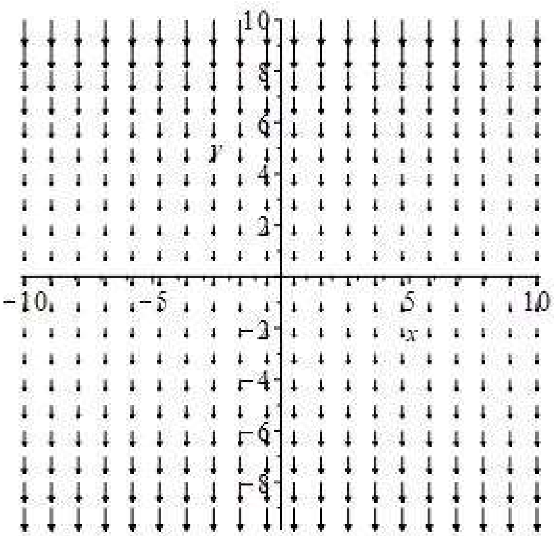
e. None of these. They all give the same limit.

Solution: (a) $\displaystyle\lim_{\substack{y=mx\\x\to 0}} \frac{x^2y^2}{x^3+y^6} = \lim_{x\to 0} \frac{x^2m^2x^2}{x^3+m^6x^6} = \lim_{x\to 0} \frac{x}{1+m^6x^3} = 0$ (b) $\displaystyle\lim_{\substack{x=0\\y\to 0}} \frac{x^2y^2}{x^3+y^6} = \lim_{y\to 0} \frac{0}{0+y^6} = 0$

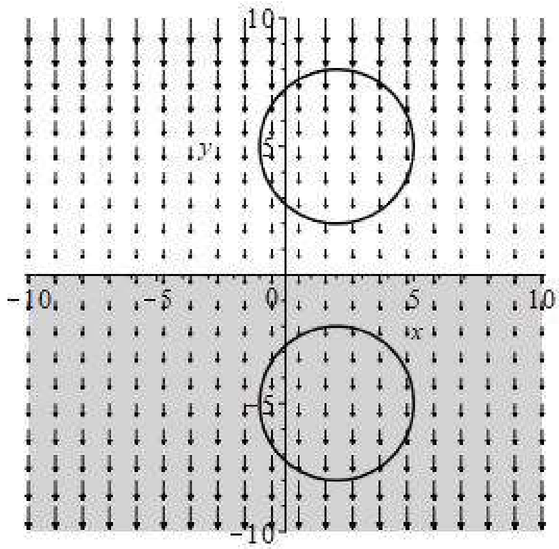
(c) $\displaystyle\lim_{\substack{x=y^2\\y\to 0}} \frac{x^2y^2}{x^3+y^6} = \lim_{y\to 0} \frac{y^4y^2}{y^6+y^6} = \lim_{y\to 0} \frac{y^6}{2y^6} = \frac{1}{2}$ (d) $\displaystyle\lim_{\substack{y=x^2\\x\to 0}} \frac{x^2y^2}{x^3+y^6} = \lim_{x\to 0} \frac{x^2x^4}{x^3+x^{12}} = \lim_{x\to 0} \frac{x^3}{1+x^9} = 0$

Work Out: (Points indicated. Part credit possible. Show all work.)

10. (5 points) Here is the plot of a vector field $\vec{F}$ in $\mathbb{R}^2$.
Shade in the region where $\vec{\nabla} \cdot \vec{F} > 0$. Explain why.



Solution: On the bottom half of the plot larger arrows point out than in on each circle. So on the bottom, $\vec{\nabla} \cdot \vec{F} > 0$.



11. (20 points) Find a scalar potential, f, for $\vec{F} = \langle yz^2 - 2xz, xz^2 - 3y^2z, 2xyz - x^2 - y^3 + 2z\rangle$ or show one does not exist. Explain all steps neatly and clearly.

Solution: $\vec{\nabla}f = \vec{F}$ (1) $\partial_x f = yz^2 - 2xz$ (2) $\partial_y f = xz^2 - 3y^2 z$ (3) $\partial_z f = 2xyz - x^2 - y^3 + 2z$

(1) $\Rightarrow$ $f = xyz^2 - x^2 z + g(y,z)$

(2) $\Rightarrow$ $\partial_y f = xz^2 - 3y^2 z = xz^2 + \partial_y g$ $\quad \partial_y g = -3y^2 z$ $\quad g = -y^3 z + h(z)$ $\quad f = xyz^2 - x^2 z - y^3 z + h(z)$

(3) $\Rightarrow$ $\partial_z f = 2xyz - x^2 - y^3 + 2z = 2xyz - x^2 - y^3 + \dfrac{dh}{dz}$ $\quad \dfrac{dh}{dz} = 2z$ $\quad h = z^2$

$$f = xyz^2 - x^2 z - y^3 z + z^2$$

12. (25 points) Find the largest and smallest values of the function $f(x,y,z) = xyz$ on the ellipsoid $x^2 + 4y^2 + 16z^2 = 48$.

Solution Method 1: Lagrange Multipliers:
Let $g = x^2 + 4y^2 + 16z^2$.

$$\vec{\nabla}f = \langle yz, xz, xy \rangle \qquad \vec{\nabla}g = \langle 2x, 8y, 32z \rangle$$

Lagrange equations: $\vec{\nabla}f = \lambda\vec{\nabla}g$

$$yz = \lambda 2x \qquad xz = \lambda 8y \qquad xy = \lambda 32z$$

Multiply first equation by x. Second by y. Third by z.

$$xyz = \lambda 2x^2 \qquad xyz = \lambda 8y^2 \qquad xyz = \lambda 32z^2$$

Equate and divide by 2λ:

$$x^2 = 4y^2 = 16z^2$$

Substitute into the elipsoid:

$$x^2 + x^2 + x^2 = 48 \qquad x^2 = 16 \qquad x = \pm 4 \qquad y = \pm 2 \qquad z = \pm 1$$

The function values are

$$f = xyz = (\pm 4)(\pm 2)(\pm 1) = \pm 8$$

Maximum is $f = 8$. Minimum is $f = -8$.

Solution Method 2: Eliminate a Variable:
It is easier to extremize $F = f^2 = x^2y^2z^2$ and then take a square root.
We solve the constraint for $x^2 = 48 - 4y^2 - 16z^2$ and plug into F:

$$F = (48 - 4y^2 - 16z^2)y^2z^2 = 48y^2z^2 - 4y^4z^2 - 16y^2z^4$$

$$F_y = 96yz^2 - 16y^3z^2 - 32yz^4 = 16yz^2(6 - y^2 - 2z^2) = 0$$

$$F_z = 96y^2z - 8y^4z - 64y^2z^3 = 8y^2z(12 - y^2 - 8z^2) = 0$$

Case 1: $y = 0$ Then $f = 0$. Note: x and z are anything satisfying $x^2 + 16z^2 = 48$.
Case 2: $z = 0$ Then $f = 0$. Note: x and y are anything satisfying $x^2 + 4y^2 = 48$.
Case 3: $y \neq 0$ and $z \neq 0$ Then

$$y^2 + 2z^2 = 6 \qquad (1)$$

$$y^2 + 8z^2 = 12 \qquad (2)$$

(2) - (1) says: $6z^2 = 6$ or $z = \pm 1$.
Then (1) says: $y^2 = 4$ or $y = \pm 2$.
Then the constraint says: $x^2 = 48 - 4y^2 - 16z^2 = 48 - 16 - 16 = 16$ or $x = \pm 4$
The function values are

$$f = xyz = (\pm 4)(\pm 2)(\pm 1) = \pm 8$$

Maximum is $f = 8$. Minimum is $f = -8$.
The $f = 0$ values from Cases 1 and 2 don't matter.