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- Start by printing your name in the above box and **check your section** in the box to the left.
- Do not detach pages from this exam packet or unstaple the packet.
- Please write neatly. Answers which are illegible for the grader cannot be given credit.
- **Show your work.** Except for multiple choice problems, we need to see details of your computation.
- No notes, books, calculators, computers, or other electronic aids can be allowed.
- You have 90 minutes time to complete your work.

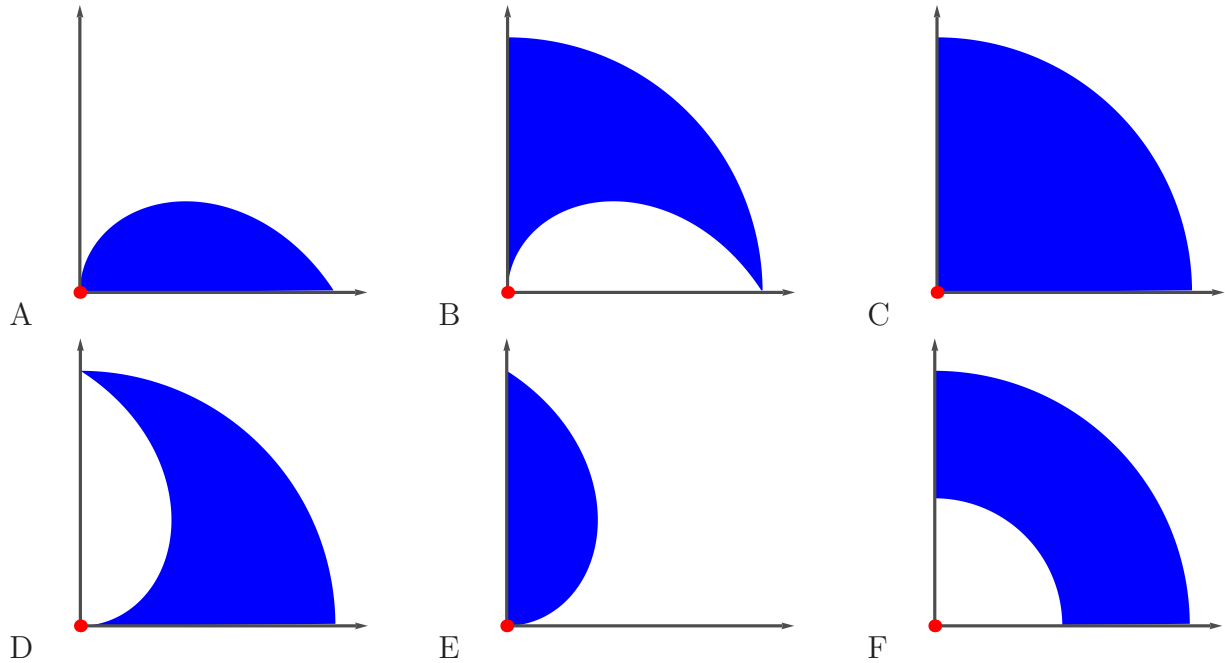
1		20
2		10
3		10
4		10
5		10
6		10
7		10
8		10
9		10
10		10
Total:		110

Problem 1) True/False questions (20 points), no justifications needed

- 1) T F If $f(x, y) = 1$ is a curve, and near $(2, 3)$ one can write y as a function of x , then $y' = -f_y(2, 3)/f_x(2, 3)$.
- 2) T F If $\iint_R f(x, y) dA = 0$, then the function $f(x, y)$ is everywhere zero on $R = \{x^2 + y^2 \leq 1\}$.
- 3) T F The directional derivative in the direction of the gradient is $|\nabla f|$.
- 4) T F The linearization of $f(x, y) = x^3 + y^3$ at $(1, 1)$ is the quadratic function $L(x, y) = 3x^2 + 3y^2$.
- 5) T F The function $f(x, y) = x^2 + y^2$ satisfies the partial differential equation $D = f_{xx}f_{yy} - f_{xy}^2 = 1$.
- 6) T F The function x^2y^2 has no local minimum at $(0, 0)$ because the discriminant function D is zero there.
- 7) T F The double integral $\int_0^{\pi/4} \int_0^2 r^3 dr d\theta$ is the volume of the part of a solid cylinder $x^2 + y^2 \leq 4$ which is below the paraboloid $z = x^2 + y^2$ and above the xy plane.
- 8) T F The gradient of $f(x, y, z)$ at (x_0, y_0, z_0) is perpendicular to the level surface of f through (x_0, y_0, z_0) .
- 9) T F If $f(x, y, z) = 3x - 4z$, then the minimal possible directional derivative $D_{\vec{u}}f$ at any point in space is -5 .
- 10) T F If (x, y) is not a critical point, then the directional derivative $D_{\vec{v}}f$ can take both positive and negative values for different choices of \vec{v} .
- 11) T F Using linearization of $f(x, y) = x/y$ we can estimate $1.01/1.001 = f(1.01, 1.001) \sim 1 + 0.01 - 0.001 = 1.009$.
- 12) T F If $(0, 0)$ is a critical point of $f(x, y)$ with nonzero discriminant $D = f_{xx}f_{yy} - f_{xy}^2$, we know that it is either a saddle, a global maximum or a global minimum.
- 13) T F For a rectangular region R , Fubini tells that $\int_0^2 \int_0^3 f(x, y) dx dy = \int_0^3 \int_0^2 f(x, y) dy dx$ for any continuous function $f(x, y)$.
- 14) T F If a function $f(x, y)$ has only one critical point $(0, 0)$ in $G = \{x^2 + y^2 \leq 1\}$ which is a local maximum and $f(0, 0) = 1$, then $\iint_G f(x, y) dx dy > 0$.
- 15) T F If $\vec{r}(t)$ is a curve in space for which the speed is 1 at all times and $f(x, y, z)$ is a function of three variables, then $d/dt f(\vec{r}(t)) = D_{\vec{r}'(t)}(f)$.
- 16) T F $\int_0^1 \int_0^1 f_{xy}(x, y) dy dx = f(1, 1) - f(1, 0) - f(0, 1) + f(0, 0)$.
- 17) T F If $f_{yy}(x, y) > 0$ everywhere, then f can not have any local maximum.
- 18) T F The double integral $\int_0^1 \int_0^1 x^2 - y^2 dx dy$ is the volume of the solid below the graph of $f(x, y) = x^2 - y^2$ and above the square $0 \leq x \leq 1, 0 \leq y \leq 1$ in the xy -plane.
- 19) T F For any unit vector \vec{v} and any differentiable function f , one has $D_{\vec{v}}(f) + D_{-\vec{v}}(f) = 0$.
- 20) T F The surfaces $x + y + z = 0$ and $x^2 + y^2 + z^2 + x + y + z = 0$ have the same tangent plane at $(0, 0, 0)$.

Problem 2) (10 points)

a) (6 points) Match the regions with the corresponding polar double integrals



Enter A-F	Integral of $f(r, \theta)$	Enter A-F	Integral of $f(r, \theta)$
	$\int_0^{\pi/2} \int_0^{\pi/2} f(r, \theta) r \, dr d\theta$		$\int_0^{\pi/2} \int_{\theta}^{\pi/2} f(r, \theta) r \, dr d\theta$
	$\int_0^{\pi/2} \int_0^{\theta} f(r, \theta) r \, dr d\theta$		$\int_0^{\pi/2} \int_{\pi/2-\theta}^{\pi/2} f(r, \theta) r \, dr d\theta$
	$\int_0^{\pi/2} \int_0^{\pi/2-\theta} f(r, \theta) r \, dr d\theta$		$\int_0^{\pi/2} \int_{\pi/4}^{\pi/2} f(r, \theta) r \, dr d\theta$

b) (4 points) Match the partial differential equations (PDE's) for the functions $u(t, s)$ with their names. No justifications are needed.

Enter A,B,C,D here	PDE
	$u_t + uu_s - u_{ss} = 0$
	$u_{tt} + u_{ss} = 0$

Enter A,B,C,D here	PDE
	$u_{tt} - u_{ss} = 0$
	$u_t - u_{ss} = 0$

A) Wave equation | B) Heat equation | C) Burgers equation | D) Laplace equation

Problem 3) (10 points)

a) (7 points) Find and classify all the critical points of the function

$$f(x, y) = 5 + 3x^2 + 3y^2 + y^3 + x^3 .$$

b) (3 points) Is there a global maximum or a global minimum for $f(x, y)$?

Problem 4) (10 points)

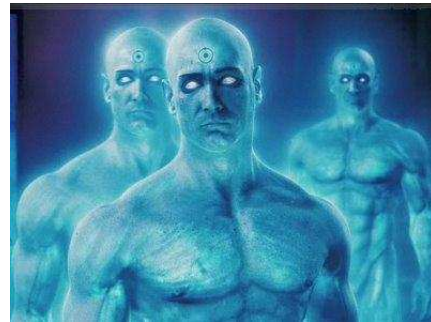
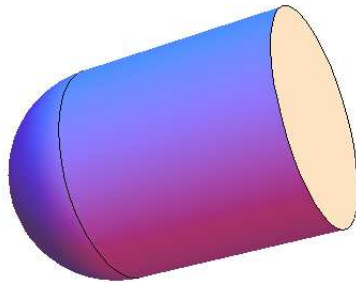
A **solid bullet** made of a half sphere and a cylinder has the volume $V = 2\pi r^3/3 + \pi r^2 h$ and surface area $A = 2\pi r^2 + 2\pi r h + \pi r^2$. Doctor Manhattan designs a bullet with fixed volume and minimal area. With $g = 3V/\pi = 1$ and $f = A/\pi$ he therefore minimizes

$$f(h, r) = 3r^2 + 2rh$$

under the constraint

$$g(h, r) = 2r^3 + 3r^2 h = 1 .$$

Use the Lagrange method to find a local minimum of f under the constraint $g = 1$.

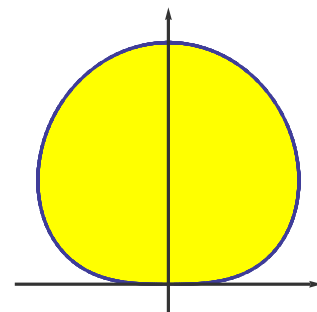


Problem 5) (10 points)

A region R in the plane shown to the right is called the “**blob of nothingness**”. It does not have any purpose nor meaning. It just sits there. The region is given in polar coordinates as $0 \leq r \leq \theta(\pi - \theta)$ for $0 \leq \theta \leq \pi$. Find the area

$$\int \int_R 1 \, dx dy$$

of this nihilistic object.



Problem 6) (10 points)

a) (4 points) If

$$f(x, y) = y \cos(x - y),$$

find equation of plane tangent to $z = f(x, y)$ at the point $(2, 2, 2)$.

b) (3 points) Find the equation of the tangent line to $f(x, y) = 2$ at $(2, 2)$.

c) (3 points) Estimate $f(2.1, 1.9)$ using linear approximation.

Problem 7) (10 points)

A **Harvard robot bee** flies along the curve

$$\vec{r}(t) = \langle t - t^3, 3t^2 - 3t \rangle$$

and measures the temperature $f(x, y)$. It flies over the target point $(0, 0)$ at time $t = 0$ and time $t = 1$. At each time, its sensor measures the temperature change $g'(t)$ where $g(t) = f(\vec{r}(t))$.

a) (5 points) Assume you knew that the gradient of f at $(0, 0)$ is $\langle a, b \rangle$. What are the values of $g'(t) = d/dt f(\vec{r}(t))$ at $t = 0$ and $t = 1$ in terms of a and b ?

b) (5 points) The bee measures $g'(0) = 3$ and $g'(1) = 3$. What is the gradient $\nabla f(0, 0) = \langle a, b \rangle$ of f at $(0, 0)$?

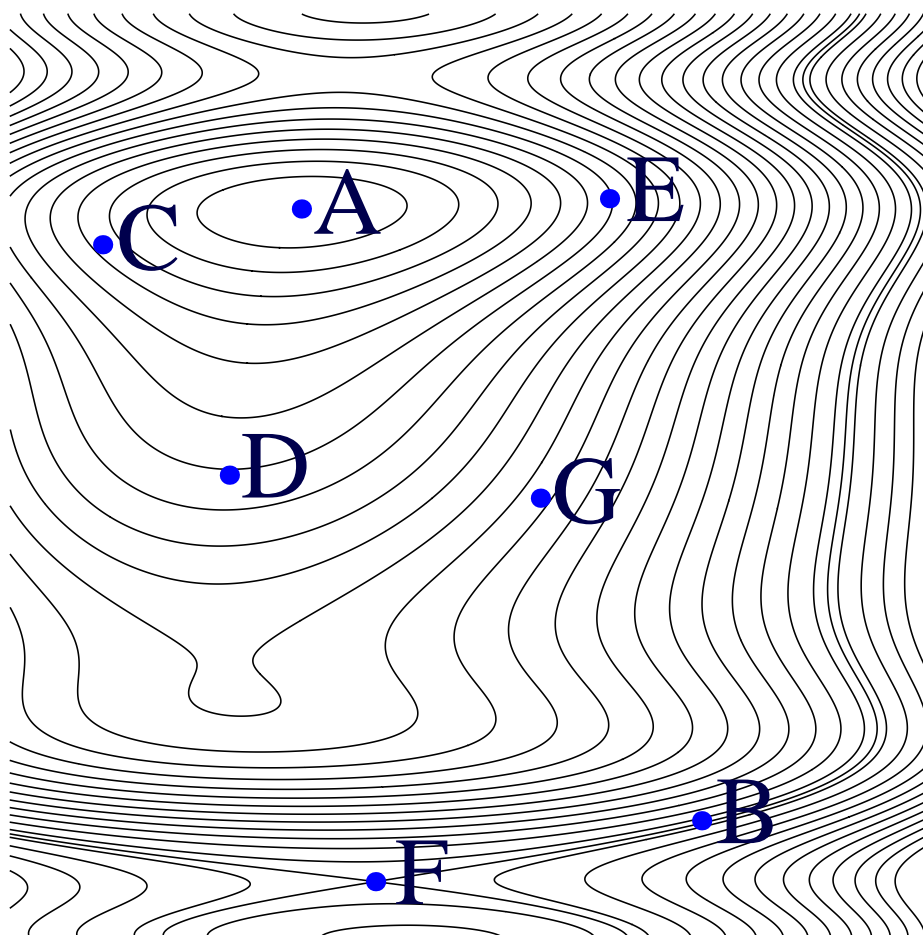


Image source: Harvard Press release on robobees.seas.harvard.edu

Problem 8) (10 points)

A function $f(x, y)$ of two variables has level curves as shown in the picture. The function values at neighboring level curves differ by 1. [No justifications are needed in this problem. Naturally, since there are less points than boxes, some of the points A-G will appear more than once, but each box will only be filled with one letter.]

Enter A-G	is a point, where ...
	$f_x(x, y) = 0$ and $f_y(x, y) \neq 0$.
	$f_y(x, y) = 0$ and $f_x(x, y) \neq 0$.
	$f(x, y)$ has either a max or a min.
	$f(x, y)$ has a saddle point.
	$f(x, y)$ has no max nor min but is extremal under a constraint $y = c$ for some c .
	$f(x, y)$ has no max nor min but is extremal under a constraint $x = c$ for some c .
	the length of the gradient vector of f is largest among all points A-G.
	$D_{\langle 1/\sqrt{2}, 1/\sqrt{2} \rangle} f(x, y) = 0$ and $D_{\langle 1/\sqrt{2}, -1/\sqrt{2} \rangle} f(x, y) \neq 0$.
	$D_{\langle 1/\sqrt{2}, -1/\sqrt{2} \rangle} f(x, y) = 0$ and $D_{\langle 1/\sqrt{2}, 1/\sqrt{2} \rangle} f(x, y) \neq 0$.
	the tangent line to the curve is $x + y = d$ for some constant d .



Problem 9) (10 points)

Evaluate the following double integral

$$\int_0^1 \int_0^{(1-x)^2} \frac{x^3}{(1-\sqrt{y})^4} dy dx .$$

Problem 10) (10 points)

A mass point with position (x, y) is attached by springs to the points $A_1 = (0, 0)$, $A_2 = (2, 0)$, $A_3 = (0, 2)$, $A_4 = (2, 3)$, $A_5 = (3, 1)$. It has the potential energy

$$f(x, y) = 31 - 14x + 5x^2 - 12y + 5y^2$$

which is the sum of the squares of the distances from (x, y) to the 5 points. Find all extrema of f using the second derivative test. The minimum of f is the position, where the mass point has the lowest energy.

