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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 problems 1-3, we need to see details of your computation.
- No notes, books, calculators, computers, or other electronic aids can be allowed.
- You have 180 minutes time to complete your work.

1		20
2		10
3		10
4		10
5		10
6		10
7		10
8		10
9		10
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11		10
12		10
13		10
14		10
Total:		150

Problem 1) True/False questions (20 points)

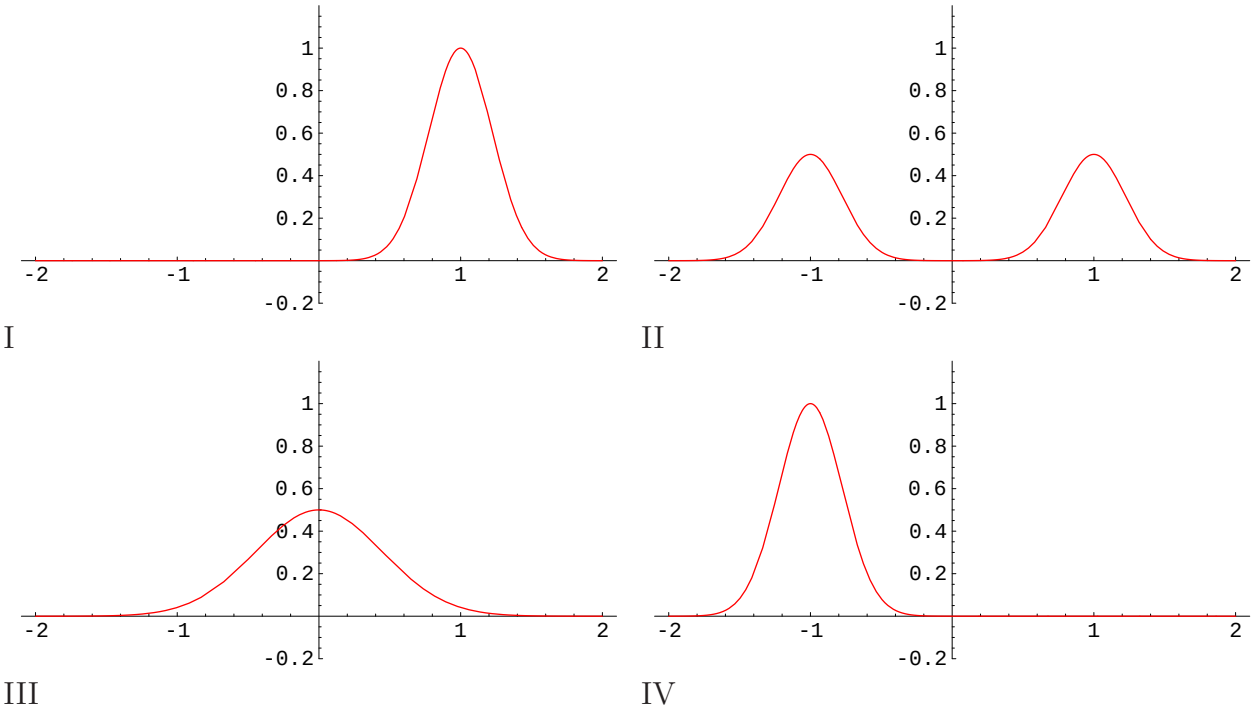
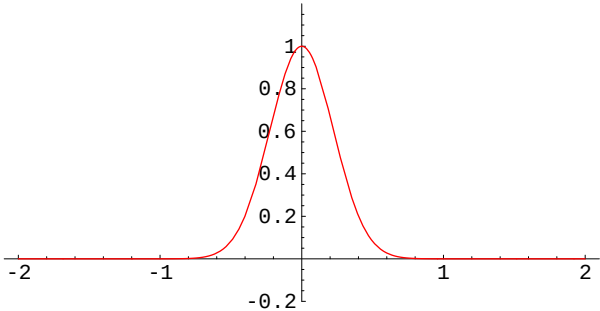
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|-----|---|--|
| 1) | ☐ T ☐ F | The distance from $(1, 2, -1)$ to $(3, -2, 1)$ is $(-2, 4, -2)$. |
| 2) | ☐ T ☐ F | The plane $y = 3$ is perpendicular to the xz plane. |
| 3) | ☐ T ☐ F | All functions $u(x, y)$ that obey $u_x = u$ at all points obey $u_y = 0$ at all points. |
| 4) | ☐ T ☐ F | The best linear approximation at $(1, 1, 1)$ to the function $f(x, y, z) = x^3 + y^3 + z^3$ is the function $L(x, y, z) = 3x^2 + 3y^2 + 3z^2$ |
| 5) | ☐ T ☐ F | If $f(x, y)$ is any function of two variables, then $\int_0^1 \left(\int_x^1 f(x, y) dy \right) dx = \int_0^1 \left(\int_y^1 f(x, y) dx \right) dy$. |
| 6) | ☐ T ☐ F | Let $C = \{(x, y) \mid x^2 + y^2 = 1\}$ be the unit circle in the plane and $\vec{F}(x, y)$ a vector field satisfying $ \vec{F} \leq 1$. Then $-2\pi \leq \int_C \vec{F} \cdot d\vec{r} \leq 2\pi$. |
| 7) | ☐ T ☐ F | Let $\vec{a}$ and $\vec{b}$ be two nonzero vectors. Then the vectors $\vec{a} + \vec{b}$ and $\vec{a} - \vec{b}$ always point in different directions. |
| 8) | ☐ T ☐ F | If all the second-order partial derivatives of $f(x, y)$ vanish at (x_0, y_0) then (x_0, y_0) is a critical point of f . |
| 9) | ☐ T ☐ F | If $\vec{a}, \vec{b}$ are vectors, then $ \vec{a} \times \vec{b} $ is the area of the parallelogram determined by $\vec{a}$ and $\vec{b}$. |
| 10) | ☐ T ☐ F | The distance between two points A, B in space is the length of the curve $\vec{r}(t) = A + t(B - A)$, $t \in [0, 1]$. |
| 11) | ☐ T ☐ F | The function $f(x, y) = xy$ has no critical point. |
| 12) | ☐ T ☐ F | The length of a curve does not depend on the chosen parameterization. |
| 13) | ☐ T ☐ F | There exists a non-zero function $f(x, y, z)$ and non-zero vector field $\vec{F}(x, y, z)$ so that $\vec{F} = \text{grad}(f)$ and $f = \text{div} \vec{F}$. |
| 14) | ☐ T ☐ F | For any numbers a, b satisfying $ a \neq b $, the vector $\langle a - b, a + b \rangle$ is perpendicular to $\langle a + b, b - a \rangle$. |
| 15) | ☐ T ☐ F | The line integral of $\vec{F}(x, y) = \langle -y, x \rangle$ along the counterclockwise oriented boundary of a region R is twice the area of R . |
| 16) | ☐ T ☐ F | There is no surface for which both the parabola and the hyperbola appear as traces. |
| 17) | ☐ T ☐ F | If $(u, v) \mapsto \vec{r}(u, v)$ is a parameterization for a surface, then $\vec{r}_u(u, v) + \vec{r}_v(u, v)$ is a vector which lies in the tangent plane to the surface. |
| 18) | ☐ T ☐ F | When using spherical coordinates in a triple integral, one needs to include the volume element $dV = \rho^2 \cos(\phi) d\rho d\phi d\theta$. |
| 19) | ☐ T ☐ F | A surface in space for which all normal vectors are parallel to each other must be part of a plane. |
| 20) | ☐ T ☐ F | A vector field $\vec{F} = \langle P(x, y), Q(x, y) \rangle$ is conservative in the plane if and only if $P_y(x, y) = Q_x(x, y)$ for all points (x, y) . |

Problem 2) (10 points)

2 a) (5 points) Fill in names of the mathematicians: Green, Stokes, Gauss, Fubini, Clairot. If there is no name associated to the theorem, write the name of the theorem.

Formula	Name of the theorem
$\int_C \vec{F} \cdot d\vec{r} = \int \int_S \text{curl}(\vec{F}) \cdot d\vec{S}$	
$f_{xy}(x, y) = f_{yx}(x, y)$	
$\int_C \vec{F} \cdot d\vec{r} = \int \int_R \text{curl}(\vec{F}) \, dx dy$	
$\int_a^b \nabla f(\vec{r}(t)) \cdot \vec{r}'(t) \, dt = f(\vec{r}(b)) - f(\vec{r}(a))$	
$\int \int_S \vec{F} \cdot d\vec{S} = \int \int \int_E \text{div}(\vec{F}) \, dV$	
$\int_a^b \int_c^d f(x, y) \, dx dy = \int_c^d \int_a^b f(x, y) \, dy dx$	

2 b) (5 points) We have a function $u(t, x)$ which is a solution to a partial differential equation. In all cases, we have $u(0, x) = e^{-x^2}$. The picture to the right shows this function $u(0, x)$. Which partial differential equation is involved, when you see the function $u(1, x)$ as a graph?



Enter I,II,III,IV here	Equation
	$u_t(x, t) = u_x(x, t)$
	$u_t(x, t) = u_{xx}(x, t)$
	$u_{tt}(x, t) = u_{xx}(x, t)$
	$u_t(x, t) = -u_x(x, t)$

Problem 3) (10 points)

- a) Find an equation for the plane Σ passing through the points $P = (1, 0, 1)$, $Q = (2, 1, 3)$ and $R = (0, 1, 5)$.
- b) Find the distance from the origin $O = (0, 0, 0)$ to Σ .
- c) Find the distance from the point P to the line through Q, R .
- d) Find the volume of the parallelepiped with vertices O, P, Q, R .

Problem 4) (10 points)

The equation $f(x, y, z) = e^{xyz} + z = 1 + e$ implicitly defines z as a function $z = g(x, y)$ of x and y .

- a) Find formulas (in terms of x, y and z) for $g_x(x, y)$ and $g_y(x, y)$.
- b) Estimate $g(1.01, 0.99)$ using linear approximation.

Problem 5) (10 points)

Find the surface area of the surface S parametrized by $\vec{r}(u, v) = \langle u, v, 2 + \frac{u^2}{2} + \frac{v^2}{2} \rangle$ for (u, v) in the disc $D = \{u^2 + v^2 \leq 1\}$.

Problem 6) (10 points)

Find the local and global extrema of the function $f(x, y)$ which is the curl of $\vec{F}(x, y) = \langle -y^4/12 + y^3/6 - y, x^4/12 - x^3/6 \rangle$ on the disc $\{x^2 + y^2 \leq 4\}$.

- a) Classify every critical point inside the disc $x^2 + y^2 < 4$.
- b) Find the extrema on the boundary $\{x^2 + y^2 = 4\}$ using the method of Lagrange multipliers.

c) Determine the global maxima and minima on all of D .

Problem 7) (10 points)

a) Given two nonzero vectors $\vec{u} = \langle a, b, c \rangle$ and $\vec{v} = \langle d, e, f \rangle$ in space, write down a formula for the cosine of the angle between them. Find a nonzero vector $\vec{v}$ that is perpendicular to $\vec{u} = \langle 3, 2, 1 \rangle$. Describe geometrically the set of all $\vec{v}$, including zero, that are perpendicular to this vector $\vec{u}$.

b) Consider a function f of three variables. Explain with a picture and a sentence what it means geometrically that $\nabla f(P)$ is perpendicular to the level set of f through P .

c) Assume the gradient of f at P is nonzero. Write a few sentences that would convince a skeptic that $\nabla f(P)$ is perpendicular to the level set of f at the point P .

d) Assume the level set of f is the graph of a function $g(x, y)$. Explain the relation between the gradient of g and the gradient of f . Especially, how do you relate the orthogonality of ∇f to the level set of f with the orthogonality of ∇g to the level set of g ?

Problem 8) (10 points)

Let R be the region inside the circle $x^2 + y^2 = 4$ and above the line $y = \sqrt{3}$. Evaluate

$$\int \int_R \frac{y}{x^2 + y^2} dA.$$

Problem 9) (10 points)

A region W in $\mathbf{R}^3$ is given by the relations

$$\begin{aligned} x^2 + y^2 &\leq z^2 \leq 3(x^2 + y^2) \\ 1 &\leq x^2 + y^2 + z^2 \leq 4 \\ x &\geq 0 \end{aligned}$$

1. Sketch the region W .
2. Find the volume of the region W .

Problem 10) (10 points)

Consider the vector field

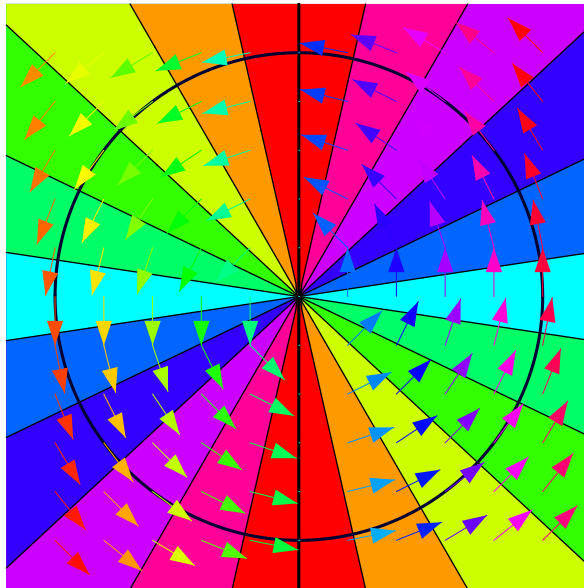
$$\vec{F}(x, y) = \left\langle \frac{-y}{x^2 + y^2}, \frac{x}{x^2 + y^2} \right\rangle$$

defined everywhere in the plane $\mathbf{R}^2$ except at the origin.

a) Let C be any closed curve which bounds a region D . Assume that $(0, 0)$ is not contained in D and does not lie on C . Explain why

$$\int_C \vec{F} \cdot d\vec{r} = 0 .$$

b) Let C be the unit circle oriented counterclockwise. What is $\int_C \vec{F} \cdot d\vec{r}$? Explain why your answer shows that there is no function f for which $\vec{F}(x, y) = \nabla f(x, y)$ everywhere.



Problem 11) (10 points)

First use rectangular, then cylindrical and finally spherical coordinates to integrate the function $f(x, y, z) = xyz$ over the solid in space described by the inequalities $0 \leq z \leq \sqrt{(1 - x^2 - y^2)}, x^2 + y^2 \leq 1, x - y \geq 0, y \geq 0$.

Problem 12) (10 points)

Let $\vec{F}(x, y)$ be a vector field in the plane given by the formula

$$\vec{F}(x, y) = \langle x^2 - 2xye^{-x^2} + 2y, e^{-x^2} + \frac{1}{\sqrt{y^4 + 1}} \rangle .$$

If C is the path which goes from from $(-1, 0)$ to $(1, 0)$ along the semi circle $x^2 + y^2 = 1$, $y \geq 0$, evaluate $\int_C \vec{F} \cdot d\vec{r}$.

Problem 13) (10 points)

In appropriate units, the charge density $\sigma(x, y, z)$ in a region in space is given by $\sigma = \nabla \cdot \vec{E} = \text{div}(\vec{E})$, where $\vec{E}$ is the electric field. Consider the cube of side lengths 1 given by $0 \leq x, y, z \leq 1$. What is the total charge in this cube if

$$\vec{E} = \langle x(1-x) \log(1+xyz), y(1-y) \tan(x^3 + y^3 + z^3), z(1-z)e^{\sqrt{x+y}} \rangle .$$

(The total charge is the integral of the charge density over the cube.)

Problem 14) (10 points)

a) By calculating the integral $\int \int_S \vec{F} \cdot d\vec{S}$ directly, find the flux of the vector field $\vec{F}(x, y, z) = \langle 0, 0, x+z \rangle$ through the sphere $x^2 + y^2 + z^2 = 9$, where the sphere is oriented with the normal pointing outward.

b) Find the flux of the vector field $\vec{F}(x, y, z) = \langle 0, 0, x+z \rangle$ through the sphere $x^2 + y^2 + z^2 = 9$ using the divergence theorem.

c) Explain in words without invoking any integral theorem, why the flux integral of the vector field $\vec{F}(x, y, z) = \langle 0, 0, x+z \rangle$ through any sphere with positive radius centered at $(0, 0, 0)$ is positive. A one or two sentence explanation is sufficient, but it should be formulated so that it makes sense to somebody who does not know calculus.