

**"I affirm my awareness of the standards of the Harvard College Honor Code."**

Name:

- Start by writing your name in the above box.
- Try to answer each question on the same page as the question is asked. If needed, use the back or the next empty page for work. If you need additional paper, write your name on it.
- Do not detach pages from this exam packet or unstaple the packet.
- Please write neatly. Answers which are illegible for the grader can not be given credit.
- No notes, books, calculators, computers, or other electronic aids can be allowed.
- You have exactly 90 minutes to complete your work.

1		20
2		10
3		10
4		10
5		10
6		10
7		10
8		10
9		10
Total:		100

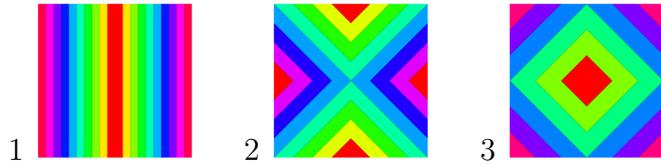
Problem 1) (20 points) No justifications are needed.

- 1)  T  F A circle of radius 20 has curvature 20.
- 2)  T  F The identity  $\vec{v} \cdot \vec{w} = |\vec{v}||\vec{w}|$  implies that  $\vec{v}$  and  $\vec{w}$  are parallel.
- 3)  T  F The cross product is associative so that  $[0, 0, 1] \times ([0, 1, 0] \times [0, 1, 0]) = ([0, 0, 1] \times [0, 1, 0]) \times [0, 1, 0]$ .
- 4)  T  F The vector  $\vec{v} = [1, 1, 1]$  containing only units is a unit vector.
- 5)  T  F The function  $f(x, y) = x^3y^2 + 1$  has a root.
- 6)  T  F There are two vectors for which the angle between the two vectors is  $-\pi/2$ .
- 7)  T  F We have  $|\vec{v} \times \vec{v}| = |\vec{v}|^2$  for all vectors  $\vec{v}$ .
- 8)  T  F The curvature of the curve  $r(t) = [2 \cos(t^3), 2 \sin(t^3)]$  is constant  $1/2$ .
- 9)  T  F It is possible to intersect a hyperbolic paraboloid with a plane and get an ellipse.
- 10)  T  F If  $\vec{T}, \vec{N}, \vec{B}$  is a TNB frame, then  $\vec{B} \cdot (\vec{T} \times \vec{N}) = 1$ .
- 11)  T  F The set of points in space which satisfy  $x^2 - 2x - y^2 - 2y + z^2 - 2z = 1$  is a one-sheeted hyperboloid.
- 12)  T  F The length of the cross product of  $\vec{v}$  and  $\vec{w}$  can be larger than  $|\vec{v}||\vec{w}|$ .
- 13)  T  F If  $\vec{v}(t), \vec{w}(t)$  are curves, then the derivative  $(\vec{v} \cdot \vec{w})'$  is  $\vec{v}' \cdot \vec{w} + \vec{v} \cdot \vec{w}'$ .
- 14)  T  F The set of points given in spherical coordinates as  $\rho^2 \sin^2(\phi) - \rho^2 \cos^2(\phi) = 1$  is a two sheeted hyperboloid.
- 15)  T  F If  $A, B, C$  are three points space lying on a line, then  $\vec{AB} \times \vec{AC}$  is the zero vector.
- 16)  T  F The line  $\vec{r}(t) = [3t, 4t, 0]$  hits the plane  $-4x + 3y = 10$  at a right angle.
- 17)  T  F The surface given in  $(r, \theta, z)$  coordinates as  $r = \cos(\theta)$  is an elliptic paraboloid.
- 18)  T  F If in spherical coordinates a point is given by  $(\rho, \theta, \phi) = (1, 3\pi/2, \pi/2)$ , then its rectangular coordinates are  $(x, y, z) = (0, -1, 0)$ .
- 19)  T  F The point  $(1, -1)$  in  $\mathbb{R}^2$  has the polar coordinates  $(r, \theta) = (\sqrt{2}, 7\pi/4)$ .
- 20)  T  F The surface given in spherical coordinates as  $\rho \sin^2(\phi) = \cos(\phi)$  is a paraboloid.

Problem 2) (10 points) No justifications are needed in this problem.

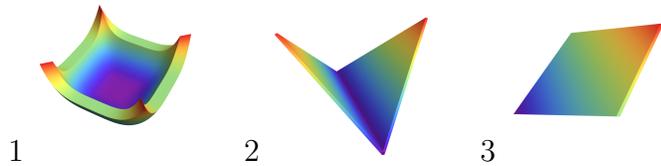
In every sub-problem, each of the numbers 0,1,2,3 each occurs exactly once.

a) (2 points) Match functions  $g$  with their xy-contour plots. Enter 0 if there is no match.



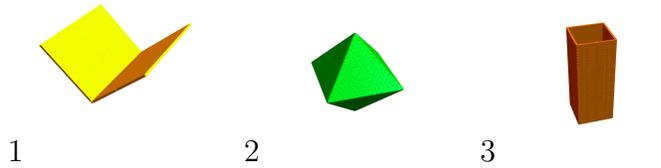
Function $g(x, y) =$	0,1,2, or 3
$ x  -  y $	
$ x $	
$ y $	
$ x  +  y $	

b) (2 points) Match the graphs of the functions  $f(x, y)$ . Enter 0 if there is no match.



Function $f(x, y) =$	0,1,2, or 3
$x + y$	
$ x + y $	
$x^2y$	
$x^4 + y^4$	

c) (2 points) Match the surfaces  $g(x, y, z) = c$ . Enter 0 if there is no match.



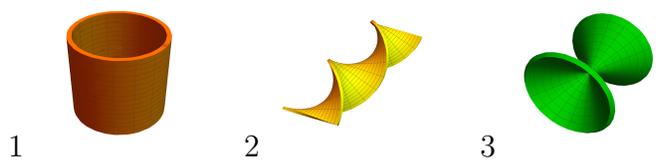
Function $g(x, y, z) =$	0,1,2, or 3
$ x  +  y  +  z  = 1$	
$ x  +  y  = 1$	
$z -  x  = 0$	
$ x  -  y  = 1$	

d) (2 points) Match the space curves with the parametrizations. Enter 0 if there is no match.



Parametrization $\vec{r}(t) =$	0,1,2, or 3
$[\cos(t), t, \sin(t)]$	
$[t + \cos(3t), 1/t, t + \sin(3t)]$	
$[\sin(t), t, t^3]$	
$[0, \sin(t/2) \cos(t), \sin(t/2) \sin(t)]$	

e) (2 points) Match the parametrized surfaces. Enter 0 if there is no match.



Parametrization $\vec{r}(u, v) =$	0-3
$[u \cos(v), u, u \sin(v)]$	
$[u \cos(v), v, u \sin(v)]$	
$[\cos(v), \sin(v) \cos(u), 2 \sin(v) \sin(u)]$	
$[\cos(v), \sin(v), u]$	

Problem 3) (10 points)

We asked 6 Disney figures to give us their most favorite multi-variable algebra calculation problem. Solve their problems! Each is worth 2 points.

a) **Minnie** would love you to compute  $([3, 4, 12] \cdot [12, 3, 4])^2 + |[3, 4, 12] \times [12, 3, 4]|^2$

Answer:

b) **Mickey** wants to know  $([1, 1, 1] \times [1, -1, 1]) \cdot [1, 1, -1]$

Answer:

c) **Goofy** wants to goof with  $([1, 0, 0] \times [1, 0, 0]) + ([1, 0, 0] \cdot [1, 0, 0])$

Answer:

d) **Donald** demands to know  $([1, 2, 3] \times [3, 2, 1]) \cdot [1, 0, 0]$

Answer:

e) **Daisy** wonders  $|[1, 1, 1]|^{|[0, 1, 0]|} / |[1, 1, 1]|$

Answer:

f) **Pluto** gets a kick out of  $|[1, 0, 0] + [0, 1, 0] - [0, 0, 1]|^2$

Answer:



Oliver's Disney figures during a meeting on what a new music video should be like.

Problem 4) (10 points)

a) (3 points) Find the equation  $ax + by + cz = d$  of the plane with normal vector  $\vec{n} = [3, 4, 5]$  passing through the point  $P = (4, 5, 6)$ .

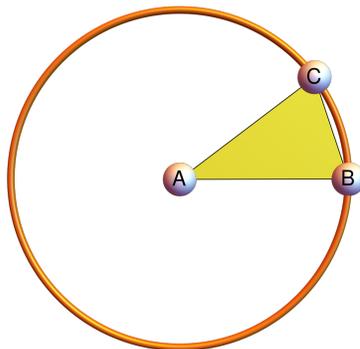
b) (4 points) Parametrize the plane you found in a).

c) (3 points) Parametrize the line through  $P$  containing the vector  $\vec{n}$ .

Problem 5) (10 points)

a) (5 points) Use the cross product to verify that the triangle  $ABC$  with  $A = (0, 0, 0)$ ,  $B = (1, 0, 0)$  and  $C = (\cos(\alpha), \sin(\alpha), 0)$  has area  $\sin(\alpha)/2$ .

b) (5 points) What is the distance of the point  $B$  to the line through  $A$  and  $C$ ? The answer will depend of course on  $\alpha$ .



Problem 6) (10 points)

In the recent **top gun movie**, Maverick's fighter jet moves along the curve

$$\vec{r}(t) = \left[ t, \sqrt{2}\frac{t^3}{3}, \frac{t^5}{5} \right].$$

a) (5 points) Find the arc length which the jet traces from  $t = -1$  to  $t = 1$ .

b) (5 points) What is the curvature of the curve at  $t = 0$ ?



Problem 7) (10 points)

On a surreal world created by **René Magritte**, one can see a floating stone. This art could have motivated the **Haleluja mountains** in the Avatar movie. We of course all wait impatiently for the new Avatar 2022 movie.

Assume the stone has the property that it is subject to an acceleration

$$\vec{r}''(t) = [\cos(t), 0, 3 + \sin(1000t)]$$

and assume the stone is initially at position  $\vec{r}(0) = [0, 0, 42]$  and that the initial velocity is  $\vec{r}'(0) = [1, 0, 0]$ . Find the path  $\vec{r}(t)$  of the stone.



This photo of this Magritte picture was captured on June 16th by Oliver.

Problem 8) (10 points)

You know that the volume  $V$  of a parallel epiped with base points  $A, B, C, D$  and top points  $P = A + \vec{u}, Q = B + \vec{u}, R = C + \vec{u}, S = D + \vec{u}$  is equal to  $V = 10$ . You also know that  $P$  has distance 5 to the base plane containing  $A, B, C, D$ . No other information is available to you.

- (5 points) What is the area of the parallelogram  $ABCD$ ?
- (5 points) Compute the distance of the line through  $A, B$  and the line through  $Q, R$ .



