Section 4.6 – Surfaces Integrals

We have defined curves in the plane in three different ways:

Explicit form: $y = f(x)$

Implicit form: $F(x, y) = 0$

Parametric vector form: $\vec{r}(t) = f(t)\hat{i} + g(t)\hat{j} \quad a \le t \le b$

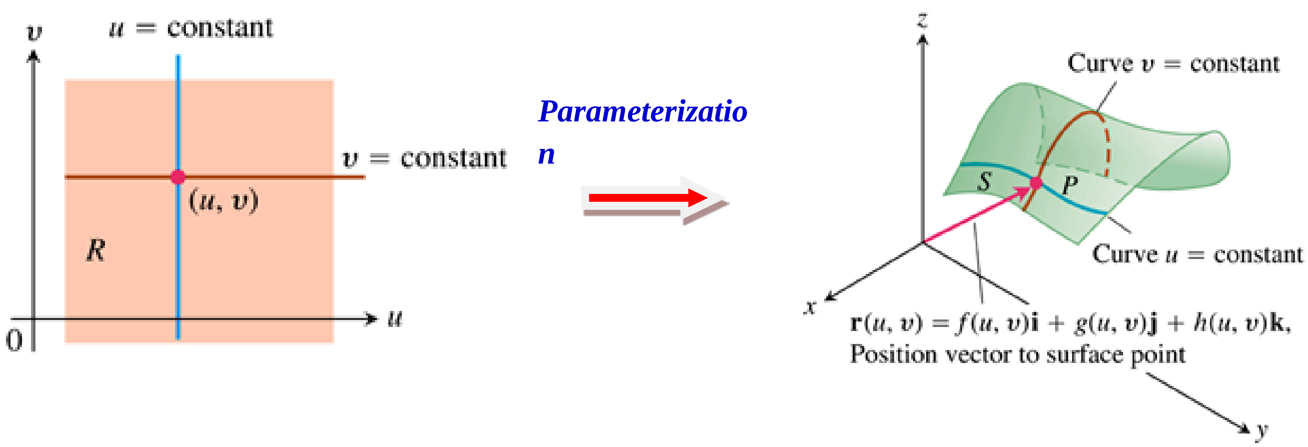
And

Explicit form: $z = f(x, y)$

Implicit form: $F(x, y, z) = 0$

Parameterizations of Surfaces

Suppose:



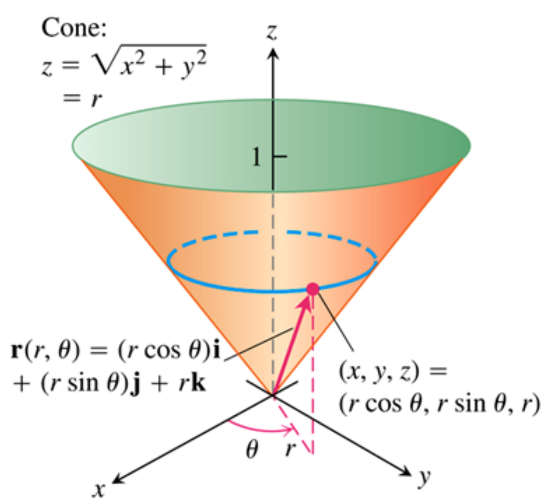
We call the range of ***r*** the ***surface*** *S* defined or traced by ***r***.

u and *v*: variable parameters

R: parameter domain

Example

Find a parameterization of the cone $z = \sqrt{x^2 + y^2}, \quad 0 \le z \le 1$



Solution

$x = r\cos\theta, \quad y = r\sin\theta$

$z = \sqrt{x^2 + y^2} = r$

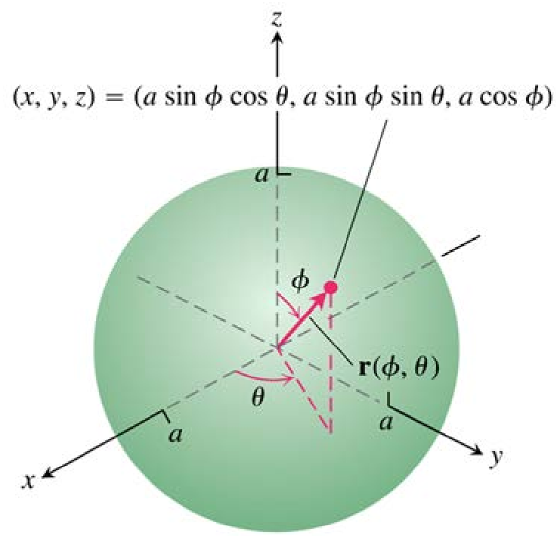
Assume $u = r \quad and \quad v = \theta$

$\vec{r}(r, \theta) = (r\cos\theta)\hat{i} + (r\sin\theta)\hat{j} + r\hat{k}$

$0 \le r \le 1, \quad 0 \le \theta \le 2\pi$

Example

Find a parameterization of the cone $x^2 + y^2 + z^2 = a^2$



Solution

A typical point $(x,\ y,\ z)$ on the sphere has

$$x = a\sin\phi\cos\theta, \quad y = a\sin\phi\sin\theta, \quad z = a\cos\phi$$

$$0 \le \phi \le 2\pi, \quad 0 \le \theta \le 2\pi$$

Taking $u = \phi$ *and* $v = \theta$

$$\vec{r}(\phi,\ \theta) = (a\sin\phi\cos\theta)\hat{\boldsymbol{i}} + (a\sin\phi\sin\theta)\hat{\boldsymbol{j}} + (a\cos\phi)\hat{\boldsymbol{k}}$$

The parameterization is one-to-one on the interior of the domain *R*, though not on its boundary "*poles*" where $\phi = 0$ *or* $\theta = \pi$

Example

Find a parameterization of the cone $x^2 + (y-3)^2 = 9, \quad 0 \le z \le 5$

Solution

$$x = r\cos\theta, \quad y = r\sin\theta, \quad z = z$$

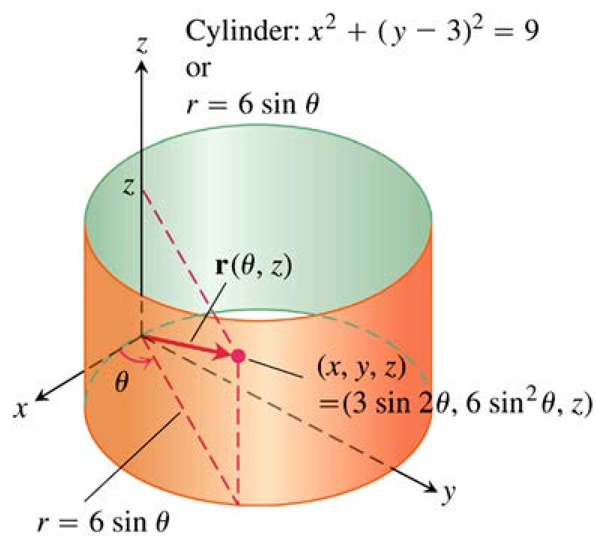
$$x^2 + y^2 - 6y + 9 = 9$$

$$x^2 + y^2 - 6y = 0$$

$$r^2 - 6r\sin\theta = 0$$

$$r(r - 6\sin\theta) = 0$$

$$r = 6\sin\theta, \quad 0 \le \theta \le \pi$$



A typical point on the cylinder has

$$\begin{cases} x = r\cos\theta = 6\sin\theta\cos\theta = 3\sin 2\theta \\ y = r\sin\theta = 6\sin^2\theta \\ z = z \end{cases}$$

Taking $u = \theta$ *and* $v = z$

$$\vec{r}(\theta,\ z) = (3\sin 2\theta)\hat{\boldsymbol{i}} + \left(6\sin^2\theta\right)\hat{\boldsymbol{j}} + z\hat{\boldsymbol{k}} \quad 0 \le \theta \le \pi, \quad 0 \le z \le 5$$

Surface Area

Calculating the area of a curved surface S based on the parameterization

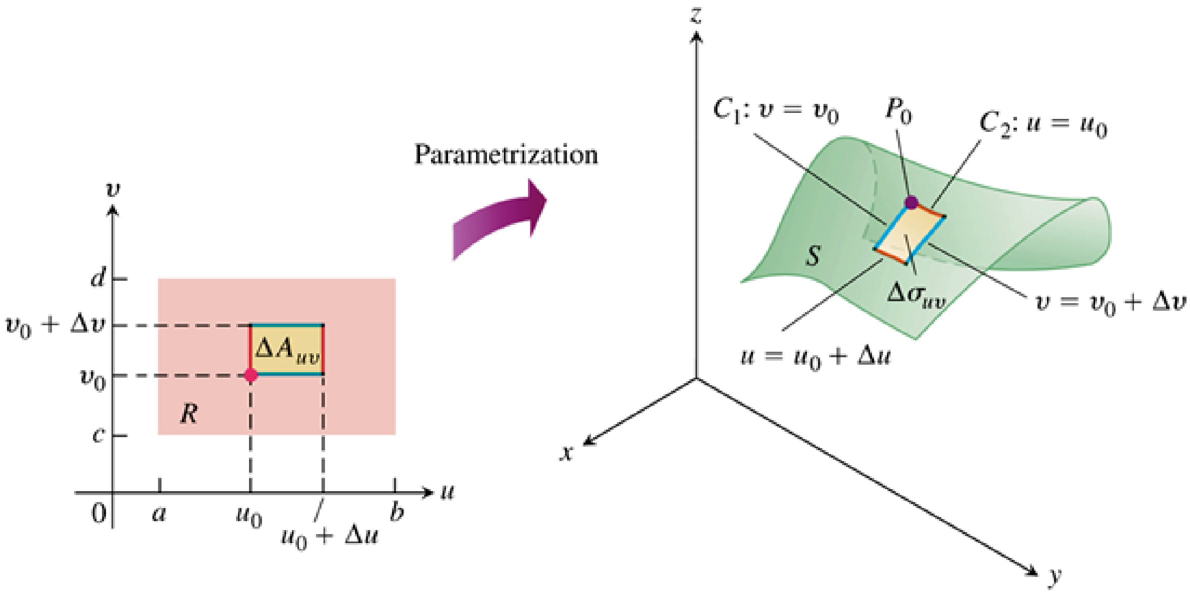
$$\vec{r}(u,\ v) = f(u,\ v)\hat{i} + g(u,\ v)\hat{j} + h(u,\ v)\hat{k}, \quad a \le u \le b, \quad c \le v \le d$$

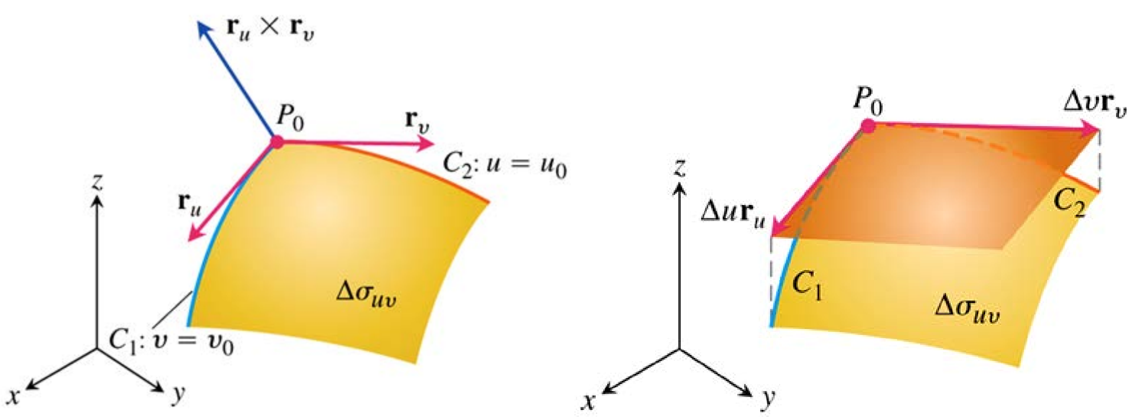
The definition of smoothness involves the partial derivatives of $\vec{r}$ with respect to u and v:

$$\vec{r}_u = \frac{\partial \vec{r}}{\partial u} = \frac{\partial f}{\partial u}\hat{i} + \frac{\partial g}{\partial u}\hat{j} + \frac{\partial h}{\partial u}\hat{k} \qquad\qquad \vec{r}_v = \frac{\partial \vec{r}}{\partial v} = \frac{\partial f}{\partial v}\hat{i} + \frac{\partial g}{\partial v}\hat{j} + \frac{\partial h}{\partial v}\hat{k}$$

Definition

A ***parameterized*** surface $\vec{r}(u,v) = f(u,v)\hat{i} + g(u,v)\hat{j} + h(u,v)\hat{k}$ is smooth if $\vec{r}_u$ and $\vec{r}_v$ are continuous and $\vec{r}_u \times \vec{r}_v$ is never zero on the interior of the parameter domain.





Definition

The area of the smooth surface

$$\vec{r}(u,\ v)=f(u,\ v)\hat{i}+g(u,\ v)\hat{j}+h(u,\ v)\hat{k}, \quad a\le u\le b, \quad c\le v\le d$$

is $$Area=\iint_R \left|\vec{r}_u\times\vec{r}_v\right| dA = \int_c^d\int_a^b \left|\vec{r}_u\times\vec{r}_v\right| dudv$$

Surface area Differential for a Parameterized Surface

$$d\sigma=\left|\vec{r}_u\times\vec{r}_v\right| dudv \qquad \iint_S d\sigma$$

Surface area differential

Differntial formula for surface area

Example

Find the surface area of the cone $z=\sqrt{x^2+y^2}, \quad 0\le z\le 1$

Solution

$x=r\cos\theta, \quad y=r\sin\theta$, and $z=\sqrt{x^2+y^2}=r$

$\vec{r}(r,\ \theta)=\langle r\cos\theta,\ r\sin\theta,\ r\rangle$

$\vec{r}_r=\langle\cos\theta,\ \sin\theta,\ 1\rangle$

$\vec{r}_\theta=\langle -r\sin\theta,\ r\cos\theta,\ 0\rangle$

$0\le r\le 1, \quad 0\le\theta\le 2\pi$

$$\begin{aligned}\vec{r}_r\times\vec{r}_\theta &= \begin{vmatrix}\hat{i} & \hat{j} & \hat{k}\\ \cos\theta & \sin\theta & 1\\ -r\sin\theta & r\cos\theta & 0\end{vmatrix}\\ &=-(r\cos\theta)\hat{i}-(r\sin\theta)\hat{j}+\left(r\cos^2\theta+r\sin^2\theta\right)\hat{k}\\ &=\langle -r\cos\theta,\ \ -r\sin\theta,\ r\rangle\end{aligned}$$

$$\begin{aligned}\left|\vec{r}_r\times\vec{r}_\theta\right| &= \sqrt{r^2\cos^2\theta+r^2\sin^2\theta+r^2}\\ &=\sqrt{r^2+r^2}\\ &=\underline{r\sqrt{2}}\end{aligned}$$

$$A=\int_0^{2\pi}\int_0^1 \left|\vec{r}_r\times\vec{r}_\theta\right|\,drd\theta$$

$$=\int_0^{2\pi}d\theta\quad\int_0^1\sqrt{2}\,r\,dr$$

$$=\frac{\sqrt{2}}{2}(2\pi)\left(r^2\right)\Big|_0^1$$

$$\boxed{=\pi\sqrt{2}\ \ units^2}$$

Example

Find the surface area of a sphere of radius a.

Solution

$$\vec{r}(\phi,\ \theta)=(a\sin\phi\cos\theta)\hat{i}+(a\sin\phi\sin\theta)\hat{j}+(a\cos\phi)\hat{k}$$

$$\vec{r}_\phi=\langle a\cos\phi\cos\theta,\ \ a\cos\phi\sin\theta,\ \ -a\sin\phi\rangle$$

$$\vec{r}_\theta=\langle -a\sin\phi\sin\theta,\ \ a\sin\phi\cos\theta,\ \ 0\rangle$$

$$0\le\phi\le\pi,\quad 0\le\theta\le 2\pi$$

$$\vec{r}_\phi\times\vec{r}_\theta=\begin{vmatrix}\hat{i} & \hat{j} & \hat{k}\\ a\cos\phi\cos\theta & a\cos\phi\sin\theta & -a\sin\phi\\ -a\sin\phi\sin\theta & a\sin\phi\cos\theta & 0\end{vmatrix}$$

$$=\left(a^2\sin^2\phi\cos\theta\right)\hat{i}+\left(a^2\sin^2\phi\sin^2\theta\right)\hat{j}+\left(a^2\cos\phi\sin\phi\cos^2\theta+a^2\cos\phi\sin\phi\sin^2\theta\right)\hat{k}$$

$$=\left(a^2\sin^2\phi\cos\theta\right)\hat{i}+\left(a^2\sin^2\phi\sin\theta\right)\hat{j}+\left(a^2\cos\phi\sin\phi\right)\hat{k}$$

$$\left|\vec{r}_\phi\times\vec{r}_\theta\right|=\sqrt{a^4\sin^4\phi\cos^2\theta+a^4\sin^4\phi\sin^2\theta+a^4\cos^2\phi\sin^2\phi}$$

$$=\sqrt{a^4\sin^4\phi\left(\cos^2\theta+\sin^2\theta\right)+a^4\cos^2\phi\sin^2\phi}$$

$$=\sqrt{a^4\sin^4\phi+a^4\cos^2\phi\sin^2\phi}$$

$$=\sqrt{a^4\sin^2\phi\left(\sin^2\phi+\cos^2\phi\right)}$$

$$=a^2\sin\phi$$

$$A=\int_0^{2\pi}\int_0^{\pi}a^2\sin\phi\ d\phi d\theta$$

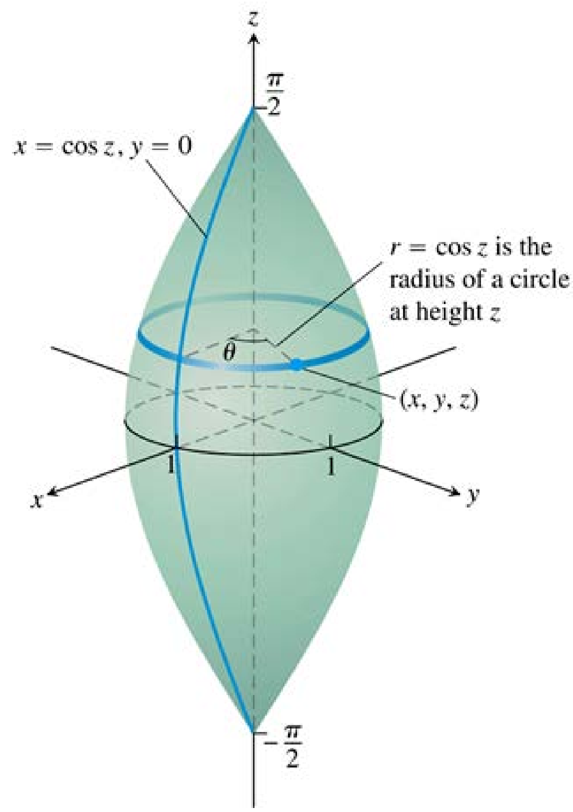
$$= a^2(-\cos\phi)\Big|_0^{\pi} \int_0^{2\pi} d\theta$$

$$= 4\pi a^2 \ \ unit^2$$

Example

Let *S* be the "football" surface formed by rotating the curve $x = \cos z, \quad y = 0, \quad -\frac{\pi}{2} \le z \le \frac{\pi}{2}$ around the *z*-axis. Find the parameterization for *S* and compute its surface area.

Solution



Let (x, y, z) be an arbitrary point on the circle.

The parameters: $u = z$ and $v = \theta$.

We have:

$$\begin{cases} x = r\cos\theta = \cos u\cos v \\ y = r\sin\theta = \cos u\sin v \\ z = u \end{cases}$$

$$\vec{r}(u, v) = (\cos u\cos v)\hat{i} + (\cos u\sin v)\hat{j} + u\hat{k}$$

$$\vec{r}_u = (-\sin u\cos v)\hat{i} - (\sin u\sin v)\hat{j} + \hat{k}$$

$$\vec{r}_v = (-\cos u\sin v)\hat{i} + (\cos u\cos v)\hat{j}$$

$$-\frac{\pi}{2} \le u \le \frac{\pi}{2}, \quad 0 \le v \le 2\pi$$

$$\vec{r}_u \times \vec{r}_v = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ -\sin u\cos v & -\sin u\sin v & 1 \\ -\cos u\sin v & \cos u\cos v & 0 \end{vmatrix}$$

$$= (-\cos u\cos v)\hat{i} - (\cos u\sin v)\hat{j} - \left(\sin u\cos u\cos^2 v + \cos u\sin u\sin^2 v\right)\hat{k}$$

$$\left|\vec{r}_u \times \vec{r}_v\right| = \sqrt{\cos^2 u\cos^2 v + \cos^2 u\sin^2 v + \left(\sin u\cos u\left(\cos^2 v + \sin^2 v\right)\right)^2}$$

$$= \sqrt{\cos^2 u\left(\cos^2 v + \sin^2 v\right) + \sin^2 u\cos^2 u}$$

$$= \sqrt{\cos^2 u\left(1 + \sin^2 u\right)}$$

$$= \cos u\sqrt{1 + \sin^2 u}$$

$$A = \int_0^{2\pi}\int_{-\pi/2}^{\pi/2} \cos u\sqrt{1+\sin^2 u}\; dudv$$

$$w = \sin u \;\Rightarrow\; dw = \cos u du \to \begin{cases} u = -\frac{\pi}{2} & \to w = -1 \\ u = \frac{\pi}{2} & \to w = 1 \end{cases}$$

$$= \int_0^{2\pi}\int_{-1}^{1} \sqrt{1+w^2}\; dwdv$$

$$= \int_0^{2\pi} \left[\frac{w}{2}\sqrt{1+w^2} + \frac{1}{2}\ln\left(w+\sqrt{1+w^2}\right)\right]_{-1}^{1} dv$$

$$= \int_0^{2\pi} \left[\frac{1}{2}\sqrt{2} + \frac{1}{2}\ln\left(1+\sqrt{2}\right) + \frac{1}{2}\sqrt{2} - \frac{1}{2}\ln\left(-1+\sqrt{2}\right)\right] dv$$

$$\ln\left(-1+\sqrt{2}\bullet\frac{1+\sqrt{2}}{1+\sqrt{2}}\right) = \ln\left(\frac{1}{1+\sqrt{2}}\right) = -\ln\left(1+\sqrt{2}\right)$$

$$= \int_0^{2\pi} \left[\sqrt{2} + \frac{1}{2}\ln\left(1+\sqrt{2}\right) + \frac{1}{2}\ln\left(1+\sqrt{2}\right)\right] dv$$

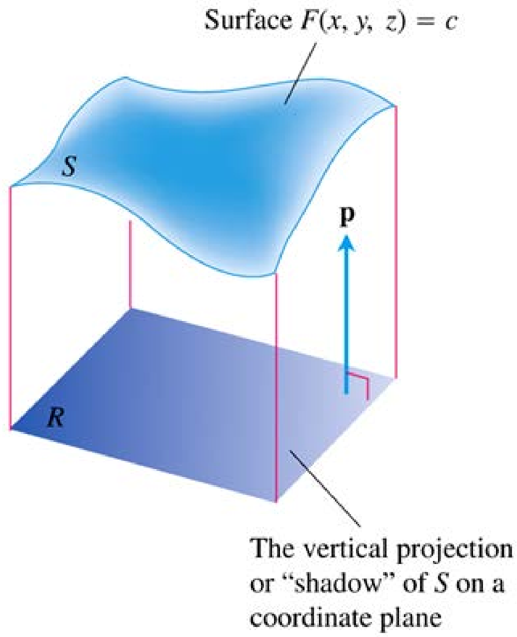
$$= \int_0^{2\pi} \left[\sqrt{2} + \ln\left(1+\sqrt{2}\right)\right] dv$$

$$= \left(\sqrt{2} + \ln\left(1+\sqrt{2}\right)\right)\; v\,\Big|_0^{2\pi}$$

$$\boxed{= 2\pi\left[\sqrt{2} + \ln\left(1+\sqrt{2}\right)\right] \quad unit^2}$$

Implicit Surfaces

Surfaces are often presented as level sets of a function $F(x,\ y,\ z)=c$ for some constant c. Such a level surface does not come with an explicit parameterization, and is called am *implicit defined surface*.



The surface is defined by the equation $F(x,y,z)=c$ and $\vec{p}$ is a unit vector normal to the plane region *R*.

$$\begin{aligned}\nabla F \bullet \vec{p} &= \nabla F \bullet \hat{k}\\ &= F_z \neq 0\end{aligned}$$

Define the parameters *u* and *v* by *u* = *x* and *v* = *y*. Then *z* = *h*(*u*, *v*) and

$$\vec{r}(u,\ v)=u\hat{i}+v\hat{j}+h(u,v)\hat{k}$$

Calculating the partial derivatives of $\vec{r}$,

$$\vec{r}_u=\hat{i}+\frac{\partial h}{\partial u}\hat{k} \quad and \quad \vec{r}_v=\hat{j}+\frac{\partial h}{\partial v}\hat{k}$$

$$\frac{\partial h}{\partial u}=-\frac{F_x}{F_z} \quad and \quad \frac{\partial h}{\partial v}=-\frac{F_y}{F_z}$$

$$\vec{r}_u=\hat{i}-\frac{F_x}{F_z}\hat{k} \quad and \quad \vec{r}_v=\hat{j}-\frac{F_y}{F_z}\hat{k}$$

$$\begin{aligned}\vec{r}_u\times\vec{r}_v &= \frac{F_x}{F_z}\hat{i}+\frac{F_y}{F_z}\hat{j}+\hat{k}\\ &= \frac{1}{F_z}\left(F_x\hat{i}+F_y\hat{j}+F_z\hat{k}\right)\\ &= \frac{\nabla F}{F_z}\end{aligned}$$

$$= \frac{\nabla F}{\nabla F \bullet \hat{k}}$$

$$= \frac{\nabla F}{\nabla F \bullet \vec{p}}$$

Therefore, the surface area differential is given by

$$d\sigma = \left|\vec{r}_u \times \vec{r}_v\right| dudv = \frac{\left|\nabla F\right|}{\left|\nabla F \bullet \vec{p}\right|} dxdy \qquad u = x \;\; and \;\; v = y$$

Formula for the Surface Area of an Implicit Surface

The area of the surface $F(x, y, z) = c$ over a closed and bounded plane region R is

$$Surface\ area = \iint_R \frac{\left|\nabla F\right|}{\left|\nabla F \bullet \vec{p}\right|}\, dA$$

Where $\vec{p} = \hat{i},\ \hat{j},\ or\ \hat{k}$ is normal to R and $\nabla F \bullet \vec{p} \neq 0$

Example

Find the area of the surface cut from the bottom of the paraboloid $x^2 + y^2 - z = 0$ by the plane $z = 4$.

Solution

Let $F(x,y,z) = x^2 + y^2 - z = 0$ and R the disk $x^2 + y^2 \le 4$

$\nabla F = 2x\hat{i} + 2y\hat{j} - \hat{k}$

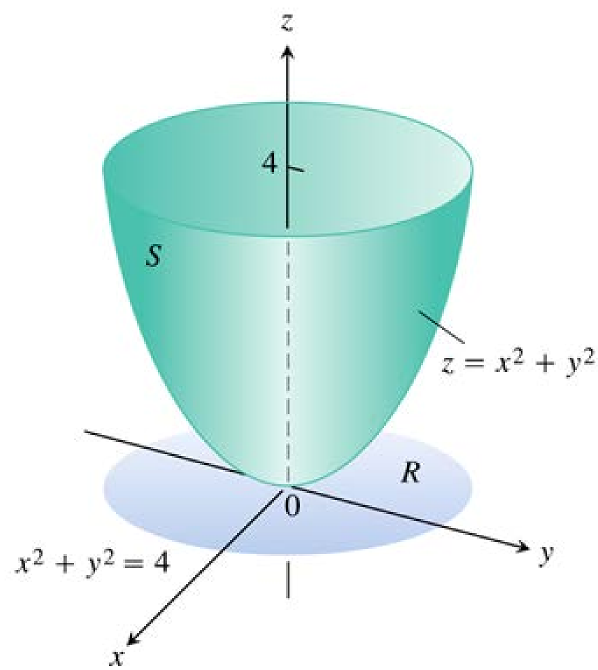
$$|\nabla F| = \sqrt{(2x)^2 + (2y)^2 + (-1)^2}$$

$$= \sqrt{4x^2 + 4y^2 + 1}$$

$$|\nabla F \bullet \vec{p}| = |\nabla F \bullet \hat{k}|$$

$$= |-1|$$

$$\underline{= 1\,|}$$



In the region R, $dA = dxdy$. Therefore,

$$Surface\ area = \iint\limits_R \frac{|\nabla F|}{|\nabla F \bullet \vec{p}|} dA$$

$$= \iint\limits_{x^2+y^2\le 4} \sqrt{4\left(x^2 + y^2\right) + 1}\ dxdy$$

$$= \int_0^{2\pi} d\theta \int_0^2 \sqrt{4r^2 + 1}\ r\ dr$$

$$= 2\pi\left(\frac{1}{8}\right)\int_0^2 \sqrt{4r^2 + 1}\ d\left(4r^2 + 1\right)$$

$$= (2\pi)\frac{1}{12}\left(4r^2 + 1\right)^{3/2} \Big|_0^2$$

$$= \frac{\pi}{6}\left(17^{3/2} - 1\right)$$

$$\boxed{= \frac{\pi}{6}\left(17\sqrt{17} - 1\right)\ unit^2}$$

Formula for the Surface Area of a Graph $z = f(x,y)$

For a graph $z = f(x,y)$ over the region R in the *xy*-plane, the surface area formula is

$$A = \iint_R \sqrt{f_x^2 + f_y^2 + 1}\ dxdy$$

Surface	***Equation***	***Explicit Description***	
		Normal Vector $\pm\left\langle -z_x,\ -z_y,\ 1\right\rangle$	***Magnitude*** $\left|\left\langle -z_x,\ -z_y,\ 1\right\rangle\right|$
Cylinder	$x^2 + y^2 = a^2$ $0 \le z \le h$	$\langle x,\ y,\ 0\rangle$	a
Cone	$z^2 = x^2 + y^2$ $0 \le z \le h$	$\left\langle \frac{x}{z},\ \frac{y}{z},\ -1\right\rangle$	$\sqrt{2}$
Sphere	$x^2 + y^2 + z^2 = a^2$	$\left\langle \frac{x}{z},\ \frac{y}{z},\ 1\right\rangle$	$\frac{a}{z}$
Paraboloid	$z = x^2 + y^2$ $0 \le z \le h$	$\langle 2x,\ 2y,\ -1\rangle$	$\sqrt{1+4\left(x^2+y^2\right)}$

Surface	***Equation***	***Parametric Description***	
		Normal Vector $\vec{r}_u \times \vec{r}_v$	***Magnitude*** $\left|\vec{r}_u \times \vec{r}_v\right|$
Cylinder	$\vec{r} = \langle a\cos u,\ a\sin u,\ v\rangle$ $0 \le u \le 2\pi,\ \ 0 \le v \le h$	$\langle a\cos u,\ a\sin u,\ 0\rangle$	a
Cone	$\vec{r} = \langle v\cos u,\ v\sin u,\ v\rangle$ $0 \le u \le 2\pi,\ \ 0 \le v \le h$	$\langle v\cos u,\ v\sin u,\ -v\rangle$	$\sqrt{2}\ v$
Sphere	$\vec{r} = \langle a\sin u\cos v,\ a\sin u\sin v,\ a\cos u\rangle$ $0 \le u \le \pi,\ \ 0 \le v \le 2\pi$	$\langle a^2\sin^2 u\cos v,\ a^2\sin^2 u\sin v,$ $a^2\sin^2 u\cos u\rangle$	$a^2\sin u$
Paraboloid	$\vec{r} = \left\langle v\cos u,\ v\sin u,\ v^2\right\rangle$ $0 \le u \le 2\pi,\ \ 0 \le v \le \sqrt{h}$	$\left\langle 2v^2\cos u,\ 2v^2\sin u,\ -v\right\rangle$	$v\sqrt{1+4v^2}$

Exercises *Section* 4.6 – Surfaces Integrals

(**1–9**) Find a parametrization of the surface:

1. The paraboloid $z = x^2 + y^2,\ z \le 4$

2. The portion of the cone $z = 2\sqrt{x^2 + y^2}$ between the planes $z = 2$ and $z = 4$

3. The sphere $x^2 + y^2 + z^2 = 8$ cuts by the plane $z = -2$

4. The plane $2x - 4y + 3z = 16$

5. The cap of the sphere $x^2 + y^2 + z^2 = 16$ for $2\sqrt{2} \le z \le 4$

6. The frustum of the cone $z^2 = x^2 + y^2$ for $2 \le z \le 8$

7. The cone $z^2 = 4\left(x^2 + y^2\right)$ for $0 \le z \le 4$

8. The portion of the cylinder $x^2 + y^2 = 9$ in the first octant, for $0 \le z \le 3$

9. The cylinder $y^2 + z^2 = 36$ for $0 \le x \le 9$

(**10–19**) Use a parametrization to express the area of the surface as a double integral. Then evaluate the integral of the portion of

10. A plane $y + 2z = 2$ inside the cylinder $x^2 + y^2 = 1$

11. A cone $z = \dfrac{\sqrt{x^2 + y^2}}{3}$ between the planes $z = 1$ and $z = \dfrac{4}{3}$

12. A cylinder $x^2 + z^2 = 10$ between the planes $y = -1$ and $y = 1$

13. Cap cut from the paraboloid $z = x^2 + y^2$ between the planes $z = 1$ and $z = 4$

14. The half cylinder $\left\{(r,\ \theta,\ z):\quad r = 4,\quad 0 \le \theta \le \pi.\quad 0 \le z \le 7\right\}$

15. The plane $z = 3 - x - 3y$ in the first octant

16. The plane $z = 10 - x - y$ above the square $|x| \le 2,\quad |y| \le 2$

17. The hemisphere $x^2 + y^2 + z^2 = 100,\quad z \ge 0$

18. A cone with base radius *r* and height *h*, where *r* and *h* are positive constants.

19. The cap of the sphere $x^2 + y^2 + z^2 = 4,\quad 1 \le z \le 2$

(**20–39**) Use a surface integral to find the area of

20. Cut from the bottom of the paraboloid $x^2 + y^2 - z = 0$ by the plane $z = 2$.

21. Portion $x^2 - 2z = 0$ that lies above the triangle bounded by the lines $x = \sqrt{3}$, $y = 0$, and $y = x$ in the *xy*-plane.

22. Cap cut from the sphere $x^2 + y^2 + z^2 = 2$ by the cone $z = \sqrt{x^2 + y^2}$.

23. Ellipse cut from the plane $z = cx$ (c a constant) by the cylinder $x^2 + y^2 = 1$.

24. From the nose of the paraboloid $x = 1 - y^2 - z^2$ by *yz*-plane.

25. First octant cut from the cylinder $y = \frac{2}{3}z^{3/2}$ by the planes $x = 1$ and $y = \frac{16}{3}$

26. Helicoid $\vec{r}(r,\ \theta) = (r\cos\theta)\hat{\boldsymbol{i}} + (r\sin\theta)\hat{\boldsymbol{j}} + \theta\hat{\boldsymbol{k}},\quad 0 \le \theta \le 2\pi,\quad 0 \le r \le 1$

27. Surface $f(x,\ y) = \sqrt{2}\,xy$ above the origin $\{(r,\ \theta):\ 0 \le r \le 2,\ 0 \le \theta \le 2\pi\}$

28. Hemisphere $x^2 + y^2 + z^2 = 9$, for $z \ge 0$ (excluding the base)

29. Frustum of the cone $z^2 = x^2 + y^2$, for $2 \le z \le 4$ (excluding the bases)

30. Area of the plane $z = 6 - x - y$ above the square $|x| \le 1$, $|y| \le 1$

31. The cone $z^2 = 4\left(x^2 + y^2\right),\quad 0 \le z \le 4$

32. The paraboloid $z = 2\left(x^2 + y^2\right),\quad 0 \le z \le 8$

33. The trough $z = x^2,\quad -2 \le x \le 2,\quad 0 \le y \le 4$

34. The part of the hyperbolic paraboloid $z = x^2 - y^2$ above the sector
$R = \left\{(r,\ \theta):\quad 0 \le r \le 4,\quad -\frac{\pi}{4} \le \theta \le \frac{\pi}{4}\right\}$

35. $f(x,\ y,\ z) = xy$, where S is the plane $z = 2 - x - y$ in the first octant

36. $f(x,\ y,\ z) = x^2 + y^2$, where S is the paraboloid $z = x^2 + y^2,\quad 0 \le z \le 4$

37. $f(x,\ y,\ z) = 25 - x^2 - y^2$, where S is the hemisphere centered at the origin with radius 5, for $z \ge 0$

38. $f(x,\ y,\ z) = e^x$, where S is the plane $z = 8 - x - 2y$ in the first octant

39. $f(x,\ y,\ z) = e^z$, where S is the plane $z = 8 - x - 2y$ in the first octant

(40–46) Evaluate the surface integrals

40. $\iint\limits_S (1 + yz)\,dS$; S is the plane $x + y + z = 2$ in the first octant.

41. $\iint_S \langle 0, y, z\rangle \cdot \vec{n}\, dS$; S is the curve surface of the cylinder $y^2 + z^2 = a^2$, $|x| \le 8$ with outward normal vectors.

42. $\iint_S (x - y + z)\, dS$; S is the entire surface including the base of the hemisphere $x^2 + y^2 + z^2 = 4$, for $z \ge 0$.

43. $\iint_S \nabla \ln|\vec{r}| \bullet \vec{n}\, dS$, where S is the hemisphere $x^2 + y^2 + z^2 = a^2$, for $z \ge 0$, and where $\vec{r} = \langle x, y, z\rangle$. Assume normal vectors point either outward or in the positive z-direction.

44. $\iint_S |\vec{r}|\, dS$, where S is the cylinder $x^2 + y^2 = 4$, for $0 \le z \le 8$, and where $\vec{r} = \langle x, y, z\rangle$. Assume normal vectors point either outward or in the positive z-direction.

45. $\iint_S xyz\, dS$, where S is the part of the plane $z = 6 - y$ that lies on the cylinder $x^2 + y^2 = 4$. Assume normal vectors point either outward or in the positive z-direction.

46. $\iint_S \frac{\langle x, 0, z\rangle}{\sqrt{x^2 + z^2}} \bullet \vec{n}\, dS$, where S is the cylinder $x^2 + y^2 = a^2$, $|y| \le 2$. Assume normal vectors point either outward or in the positive z-direction.

(**47–50**) Evaluate the surface integral $\iint_S f(x, y, z)\, dS$

47. $f(x, y, z) = x^2 + y^2$, where S is the hemisphere $x^2 + y^2 + z^2 = 36$, $z \ge 0$

48. $f(x, y, z) = y$, where S is the cylinder $x^2 + y^2 = 9$, $0 \le z \le 3$

49. $f(x, y, z) = x$, where S is the cylinder $x^2 + z^2 = 1$, $0 \le y \le 3$

50. $f(\rho, \varphi, \theta) = \cos\varphi$, where S is the part of the unit shpere in the first octant

(**51–58**) Find the flux of the vector fields across the given surface with the specified orientation

51. $\vec{F} = \frac{\vec{r}}{|\vec{r}|}$ across the sphere of radius a centered at the origin, where $\vec{r} = \langle x, y, z\rangle$. Assume the normal vectors to the surface point outward.

52. $\vec{F} = \langle x,\ y,\ z \rangle$ across the curved surface of the cylinder $x^2 + y^2 = 1$ for $|z| \le 8$

53. $\vec{F} = \langle 0,\ 0,\ -1 \rangle$ across the slanted face of the tetrahedron $z = 4 - x - y$ in the first octant; normal vectors point upward

54. $\vec{F} = \langle x,\ y,\ z \rangle$ across the slanted face of the tetrahedron $z = 10 - 2x - 5y$ in the first octant; normal vectors point upward

55. $\vec{F} = \langle x,\ y,\ z \rangle$ across the slanted face of the cone $z^2 = x^2 + y^2$ for $0 \le z \le 1$; normal vectors point upward

56. $\vec{F} = \left\langle e^{-y},\ 2z,\ xy \right\rangle$ across the curved sides of the surface

$S = \{(x,\ y,\ z):\quad z = \cos y,\quad -\pi \le y \le \pi,\quad 0 \le x \le 4\}$; normal vectors point upward.

57. $\vec{F} = \dfrac{\vec{r}}{|\vec{r}|^3}$ across the sphere of radius a centered at the origin, where $\vec{r} = \langle x,\ y,\ z \rangle$; normal vectors point outward

58. $\vec{F} = \langle -y,\ x,\ 1 \rangle$ across the cylinder $y = x^2$ for $0 \le x \le 1,\quad 0 \le z \le 4$; normal vectors point in the general direction of the positive y-axis

59. Consider the ellipsoid $\dfrac{x^2}{a^2} + \dfrac{y^2}{b^2} + \dfrac{z^2}{c^2} = 1$, where a ,b, and c are positive real numbers.

a) Show that the surface is described by the parametric equations
$\vec{r}(u,v) = \langle a\cos u \sin v,\ \ b\sin u \sin v,\ \ c\cos v \rangle$ for $0 \le u \le 2\pi,\quad 0 \le v \le \pi$

b) Write an integral for the surface area of the ellipsoid.

60. The cone $z^2 = x^2 + y^2,\quad z \ge 0$, cuts the sphere $x^2 + y^2 + z^2 = 16$ along a curve C.

a) Find the surface area of the sphere below C, for $z \ge 0$

b) Find the surface area of the sphere above C.

c) Find the surface area of the cone below C, for $z \ge 0$

61. Consider the sphere $x^2 + y^2 + z^2 = 4$ and the cylinder $(x-1)^2 + y^2 = 1$ for $z \ge 0$.

a) Find the surface area of the cylinder inside the sphere

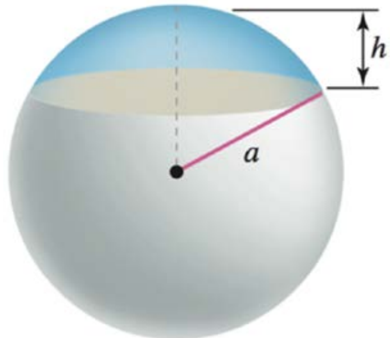
b) Find the surface area of the sphere inside the cylinder.

62. Find the upward flux of the field $\vec{F} = \langle x,\ y,\ z \rangle$ across the plane $\dfrac{x}{a} + \dfrac{y}{b} + \dfrac{z}{c} = 1$ in the first octant. Show that the flux equals c times the area if the base of the origin.

63. Consider the field $\vec{F} = \langle x,\ y,\ z \rangle$ and the cone $z^2 = \dfrac{x^2 + y^2}{a^2}$, for $0 \le z \le 1$

a) Show that when $a = 1$, the outward flux across the cone is zero.
b) Find the outward flux (away from the *z*-axis); for any $a > 0$.

64. A sphere of radius *a* is sliced parallel to the equatorial plane at a distance $a - h$ from the equatorial plane. Find the general formula for the surface area of the resulting spherical cap (excluding the base) with thickness *h*.



65. Consider the radial field $\vec{F} = \dfrac{\vec{r}}{|\vec{r}|^p}$, where $\vec{r} = \langle x,\ y,\ z \rangle$ and *p* is a real number. Let *S* be he sphere of radius *a* centered at the origin. Show that the outward flux of $\vec{F}$ across the sphere is $\dfrac{4\pi}{a^{p-3}}$. It is instructive to do the calculation using both an explicit and parametric description of the sphere.

(**66–68**) The heat flow vector field for conducting objects is $\vec{F} = -k\nabla T$, where $T(x,\ y,\ z)$ is the temperature in the object and $k > 0$ is a constant that depends on the material. Compute the outward flux of $\vec{F}$ across the following surfaces *S* for the given temperature distributions. Assume $k = 1$.

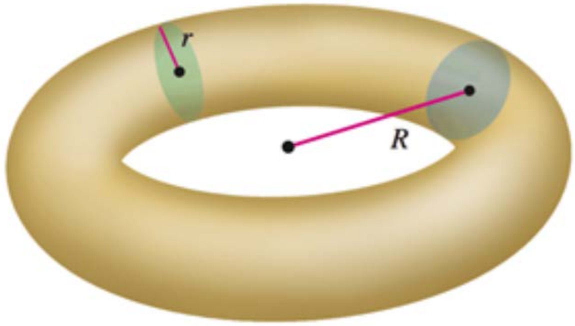
66. $T(x,\ y,\ z) = 100e^{-x-y}$; *S* consists of the faces of the cube $|x| \le 1,\quad |y| \le 1,\quad |z| \le 1$

67. $T(x,\ y,\ z) = 100e^{-x^2-y^2-z^2}$; *S* cis the sphere $x^2 + y^2 + z^2 = a^2$

68. $T(x,\ y,\ z) = -\ln\left(x^2 + y^2 + z^2\right)$; *S* cis the sphere $x^2 + y^2 + z^2 = a^2$

69. Given: $\vec{r}(u,\ v) = \langle (R + r\cos u)\cos v,\ \ (R + r\cos u)\sin v,\ \ r\sin u \rangle$

a) Show that a torus with radii $R > r$ may be described parametrically by $\vec{r}(u,\ v)$ for $0 \le u \le 2\pi,\quad 0 \le v \le 2\pi$



b) Show that the surface area of the torus is $4\pi^2 Rr$