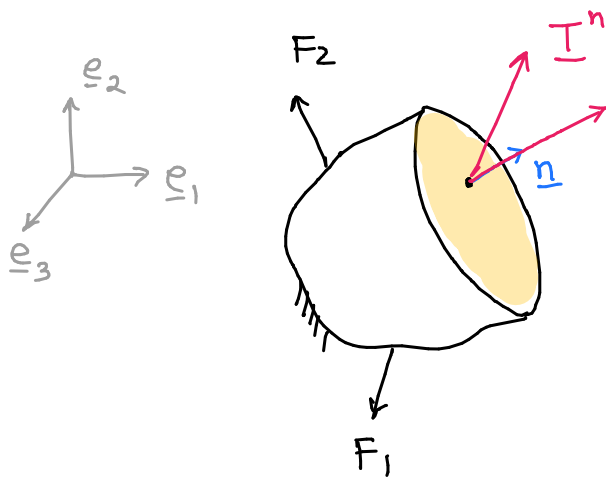


## Decomposition of traction vector

In the last lecture, we introduced the traction vector as the intensity of force at a point on a given plane.

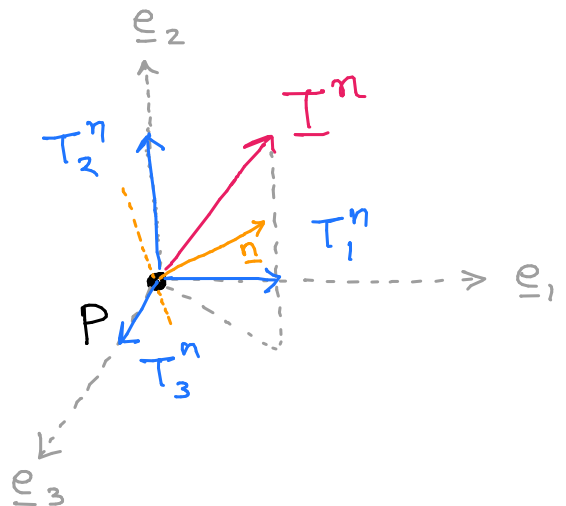


Since traction is a vector, one can obtain components of the traction vector using a choice of coordinate system.

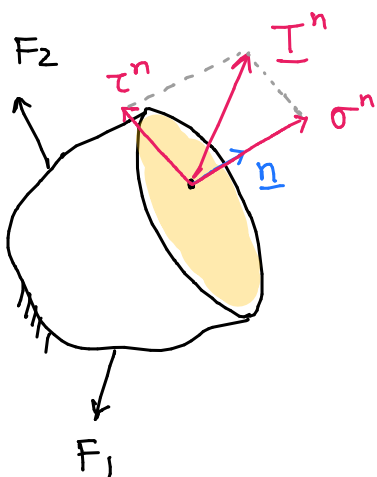
$$\underline{T}^n(\underline{x}) = T_1^n \underline{e}_1 + T_2^n \underline{e}_2 + T_3^n \underline{e}_3$$

Note that a vector is independent of the coordinate system chosen to represent its components

$$|\underline{T}^n|^2 = |T_1^n|^2 + |T_2^n|^2 + |T_3^n|^2$$



## Normal and shear components of traction



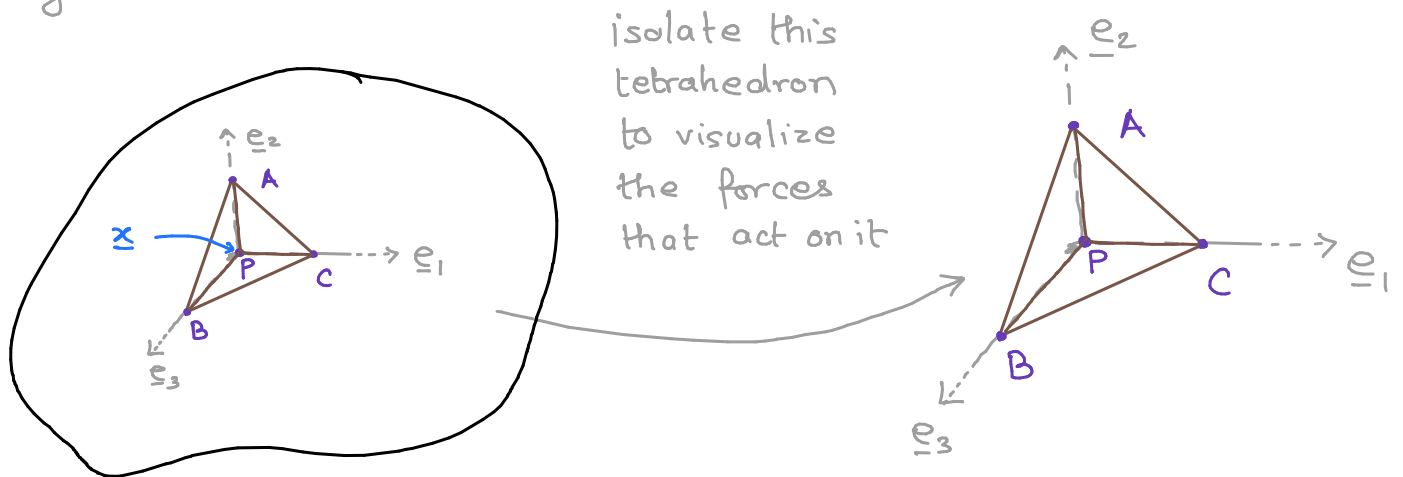
The traction vector could also be resolved along the direction of normal  $\underline{n}$  and a direction tangential to the plane of cut such that

$$|\underline{T}^n|^2 = (\sigma^n)^2 + (\tau^n)^2$$

$$\sigma^n = T_1^n n_1 + T_2^n n_2 + T_3^n n_3$$

Now we will derive how a traction vector at a point for a given plane orientation may be found using tractions on three mutually perpendicular planes at the same point

Consider a small tetrahedron at a point  $P$  inside the body

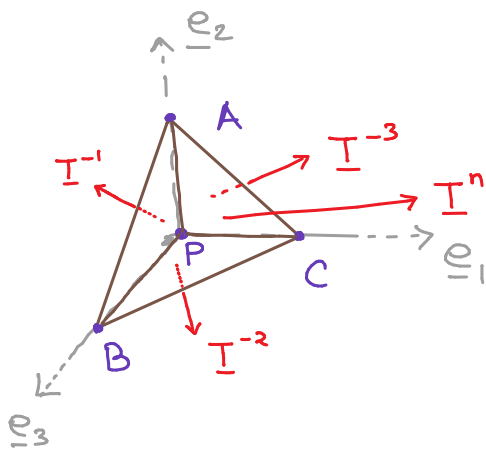


Faces of tetrahedron : Outward normals

ABC	—	$\underline{\underline{n}}$
PAB	—	$-\underline{\underline{e}}_1$
PBC	—	$-\underline{\underline{e}}_2$
PAC	—	$-\underline{\underline{e}}_3$

What are the various forces acting on this tetrahedron?

- Weight (body force) due to gravity acting on every point of the tetrahedron. The total weight of the tetrahedron can be assumed to act through its COM (center of mass)
- Internal (surface) forces acting on surfaces of the tetrahedron. These internal surface forces are applied by the rest of the body on the sides of the tetrahedron



Lets assume that the traction vector acting on each face is uniform, so we have

Plane	Outward Normal	Traction
ABC	$\underline{n}$	$\underline{T}^n$
PAB	$-\underline{e}_1$	$\underline{T}^{-1}$
PBC	$-\underline{e}_2$	$\underline{T}^{-2}$
PAC	$-\underline{e}_3$	$\underline{T}^{-3}$

For static equilibrium of the tetrahedron

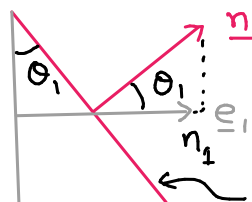
$$\sum \underline{F} = 0 \quad (\text{Resultant of all forces must be zero})$$

$$\Rightarrow \underline{T}^{-1} A_{PAB} + \underline{T}^{-2} A_{PBC} + \underline{T}^{-3} A_{PAC} + \underline{T}^n A_{ABC} + \rho V \underline{g} = \underline{0}$$

density  
volume  
acceleration vector due to gravity

We can write the area of the inclined face ABC in terms of other areas  $A_{PAB}$ ,  $A_{PBC}$ , and  $A_{PAC}$ .

For example, the area of ABC if projected along  $\underline{e}_1$ -axis is equal to  $A_{PAB}$



$$\begin{aligned} A_{PAB} &= A_{ABC} (\underline{n} \cdot \underline{e}_1) \\ &= A_{ABC} n_1 \end{aligned}$$

$$\Rightarrow \underline{\underline{T}}^{-1} A_{PAB} + \underline{\underline{T}}^{-2} A_{PBC} + \underline{\underline{T}}^{-3} A_{PAC} + \underline{\underline{T}}^n A_{ABC} + \rho V \underline{\underline{g}} = \underline{\underline{0}}$$

So we can rewrite the above relation as follows:

$$\Rightarrow \cancel{\underline{\underline{T}}^{-1} A_{ABC}} (\underline{\underline{n}} \cdot \underline{\underline{e}}_1) + \cancel{\underline{\underline{T}}^{-2} A_{ABC}} (\underline{\underline{n}} \cdot \underline{\underline{e}}_2) + \cancel{\underline{\underline{T}}^{-3} A_{ABC}} (\underline{\underline{n}} \cdot \underline{\underline{e}}_3) + \underline{\underline{T}}^n \cancel{A_{ABC}} + \rho \underline{\underline{g}} (\cancel{A_{ABC}} \cdot h) = \underline{\underline{0}}$$

$$\Rightarrow \sum_{i=1}^3 \underline{\underline{T}}^{-i} (\underline{\underline{n}} \cdot \underline{\underline{e}}_i) + \underline{\underline{T}}^n + \rho \underline{\underline{g}} h = \underline{\underline{0}}$$

Our goal is find the tractions at the point P, instead of the faces (which are not a point). So, we reduce 'h' to zero s.t. the tetrahedron shrinks to the point P

Also, note that as  $h \rightarrow 0$ , the term  $\rho \underline{\underline{g}} h \rightarrow \underline{\underline{0}}$  and we have a simple result:

$$\sum_{i=1}^3 \underline{\underline{T}}^{-i} (\underline{\underline{n}} \cdot \underline{\underline{e}}_i) + \underline{\underline{T}}^n = \underline{\underline{0}}$$

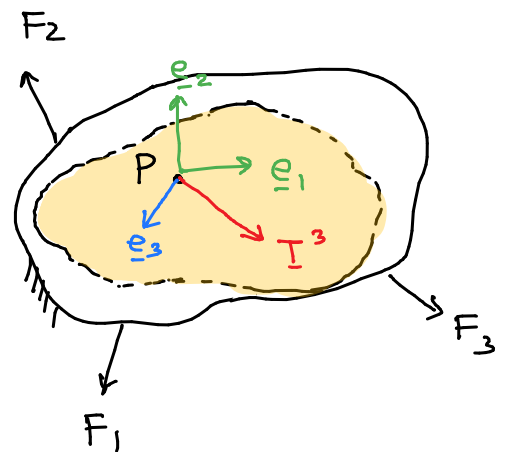
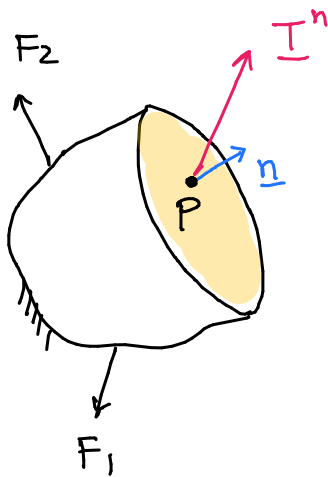
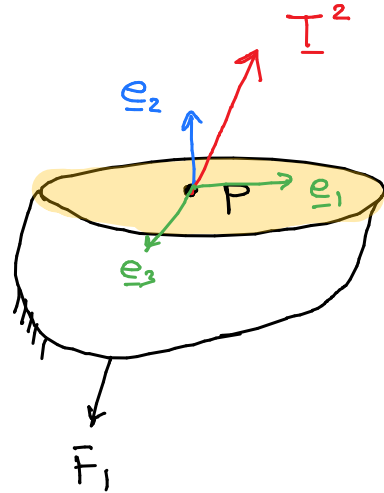
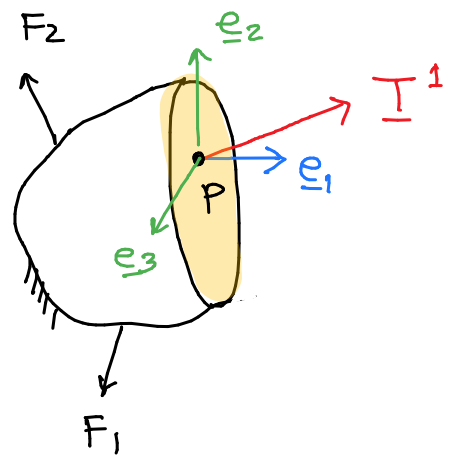
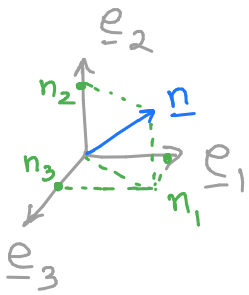
Furthermore, we know that  $\underline{\underline{T}}^i = -\underline{\underline{T}}^{-i}$  (see prev. lecture)

So, we get

$$\underline{\underline{T}}^n = \sum_{i=1}^3 \underline{\underline{T}}^i (\underline{\underline{n}} \cdot \underline{\underline{e}}_i)$$

(expressed in a coordinate system  $\underline{\underline{e}}_1, \underline{\underline{e}}_2, \underline{\underline{e}}_3$ )

If we know traction vectors on three mutually perpendicular planes, the the traction vector on any plane passing through the point P may be obtain by the above relation



$$\underline{T}^n = \underline{T}^1 n_1 + \underline{T}^2 n_2 + \underline{T}^3 n_3$$

$$\begin{bmatrix} T_1^n \\ T_2^n \\ T_3^n \end{bmatrix} = \underbrace{\begin{bmatrix} T_1^1 \\ T_2^1 \\ T_3^1 \end{bmatrix}}_{\text{Traction on plane with normal } \underline{e}_1} n_1 + \begin{bmatrix} T_1^2 \\ T_2^2 \\ T_3^2 \end{bmatrix} n_2 + \underbrace{\begin{bmatrix} T_1^3 \\ T_2^3 \\ T_3^3 \end{bmatrix}}_{\text{Traction on plane with normal } \underline{e}_3} n_3$$

Traction  
on plane with normal  $\underline{e}_1$

Traction on plane  
with normal  $\underline{e}_3$