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General Certificate of Education (Advanced Level) – Grade 12

UNIT TEST
Combined Mathematics II

Coverage: Vectors (scalars & vectors, addition, position vectors, **i**, **j** notation, scalar product, vector product – properties only) · Systems of coplanar forces acting at a point (resultant of two forces, parallelogram law, resolution of forces, resultant and equilibrium of coplanar forces at a point)

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Time: 5 hours
Part A – 2 h 30 min · Part B – 2 h 30 min
(may be taken in two sittings)

Index No. | | | | | | | |

Name : .....

School : .....

Instructions

- This paper consists of two parts: **Part A** (Questions 1–30) and **Part B** (Questions 31–46).
- **Part A:** Answer **all** questions. Write your answers **in the space provided on this paper**. Additional sheets may be used if needed.
- **Part B:** Answer **five** questions only. Write your answers **in the answer book provided**.
- Part A carries 25 marks per question (750). Part B carries 150 marks per question (750). Total 1500.
- Questions in each part become progressively more demanding.
- At the end of the allotted time, tie Part A on top of your Part B answer book and hand both to the supervisor.
- Show all working. Marks are awarded for correct method as well as correct answers.
- **i** and **j** denote unit vectors along Ox and Oy; $\mathbf{k} = \mathbf{i} \times \mathbf{j}$.

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Part	Q	Mk	Q	Mk	Q	Mk
A	1		11		21	
	2		12		22	
	3		13		23	
	4		14		24	
	5		15		25	
	6		16		26	
	7		17		27	
	8		18		28	
	9		19		29	
	10		20		30	
B	31		37		43	
	32		38		44	
	33		39		45	
	34		40		46	
	35		41			
	36		42			
				Total		

Total	
Part A (750)	
Part B (750)	
In numbers (1500)	
In words	

Code numbers	
Marking examiner	
Checked by 1	
2	
Supervised by	

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PART A

Answer **all** questions in the space provided.

1. Distinguish between a scalar quantity and a vector quantity, giving two examples of each. $ABCD$ is a quadrilateral. Simplify (i) $\overrightarrow{AB} + \overrightarrow{BC} + \overrightarrow{CD}$, (ii) $\overrightarrow{AB} - \overrightarrow{CB}$, (iii) $\overrightarrow{AB} + \overrightarrow{BC} + \overrightarrow{CA}$. **(25 marks)**

2. Let $\mathbf{a} = 3\mathbf{i} + 4\mathbf{j}$. Find $|\mathbf{a}|$, the unit vector in the direction of $\mathbf{a}$, and the vector of magnitude 10 in the direction of $\mathbf{a}$. Are $2\mathbf{i} - 6\mathbf{j}$ and $-3\mathbf{i} + 9\mathbf{j}$ parallel? Give a reason. **(25 marks)**

3. Let $\mathbf{a} = 2\mathbf{i} - \mathbf{j}$ and $\mathbf{b} = \mathbf{i} + 3\mathbf{j}$. Find $2\mathbf{a} - 3\mathbf{b}$ and $|2\mathbf{a} - 3\mathbf{b}|$. Find the scalar t for which $\mathbf{a} + t\mathbf{b}$ is parallel to $\mathbf{i}$. **(25 marks)**

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4. Resolve a vector of magnitude 10 units, making 30° with Ox, into components along Ox and Oy. A force of 50 N acts at 30° above the horizontal. Find its horizontal and vertical components. **(25 marks)**

5. Find the magnitude of the resultant of (i) forces of 3 N and 4 N acting at right angles, (ii) forces of 5 N and 8 N acting at 60° to each other. **(25 marks)**

6. Two forces, each of magnitude P, act at a point at an angle 2α. Show that their resultant is $2P\cos\alpha$ and bisects the angle between them. Find the angle between two equal forces whose resultant equals either force in magnitude. **(25 marks)**

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7. A and B are the points $(2, -1)$ and $(5, 3)$. Express $\overrightarrow{AB}$ in terms of $\mathbf{i}$ and $\mathbf{j}$ and find $|\overrightarrow{AB}|$. Points P and Q have position vectors $\mathbf{p}$ and $\mathbf{q}$. Write down the position vector of the point dividing PQ internally in the ratio $2 : 3$. **(25 marks)**

8. Find the unit vectors parallel to $5\mathbf{i} - 12\mathbf{j}$. Find the vector of magnitude 26 in the direction opposite to $5\mathbf{i} - 12\mathbf{j}$. **(25 marks)**

9. Find the scalars λ and μ such that $\lambda(2\mathbf{i} + \mathbf{j}) + \mu(\mathbf{i} - 3\mathbf{j}) = 4\mathbf{i} + 9\mathbf{j}$. **(25 marks)**

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10. Let $\mathbf{a} = 2\mathbf{i} + 3\mathbf{j}$ and $\mathbf{b} = 4\mathbf{i} - \mathbf{j}$. Find $\mathbf{a} \cdot \mathbf{b}$ and the cosine of the angle between $\mathbf{a}$ and $\mathbf{b}$. Find p such that $p\mathbf{i} + 2\mathbf{j}$ is perpendicular to $3\mathbf{i} - 4\mathbf{j}$. **(25 marks)**

11. Write down $\mathbf{i} \cdot \mathbf{i}$, $\mathbf{i} \cdot \mathbf{j}$, $\mathbf{i} \times \mathbf{j}$, $\mathbf{j} \times \mathbf{i}$ and $\mathbf{i} \times \mathbf{i}$. Using the properties of the vector product, find $(2\mathbf{i} + 3\mathbf{j}) \times (\mathbf{i} - \mathbf{j})$. **(25 marks)**

12. Forces $2\mathbf{i}+3\mathbf{j}$, $-\mathbf{i}+4\mathbf{j}$ and $3\mathbf{i}-2\mathbf{j}$ newtons act at a point. Find their resultant and its magnitude. Find the force which, together with $3\mathbf{i} - 2\mathbf{j}$ and $-5\mathbf{i} + 4\mathbf{j}$, keeps a particle in equilibrium. **(25 marks)**

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13. Forces of 10 N due east, 6 N due north, 4 N due west and 14 N due south act on a particle. Find the magnitude and direction of their resultant. **(25 marks)**

14. In a triangle ABC, D is the midpoint of BC. Show that $\overrightarrow{AB} + \overrightarrow{AC} = 2\overrightarrow{AD}$. Deduce that $\overrightarrow{AB} + \overrightarrow{AC} + 2\overrightarrow{DA} = \mathbf{0}$. **(25 marks)**

15. $\mathbf{a}$ and $\mathbf{b}$ are non-zero, non-parallel vectors. Find λ and μ if $(2\lambda - 1)\mathbf{a} + (\lambda + \mu - 3)\mathbf{b} = \mathbf{0}$. State clearly the result you use. **(25 marks)**

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16. The position vectors of A, B, C relative to O are $14\mathbf{a} - 2\mathbf{b}$, $-4\mathbf{a} + 10\mathbf{b}$ and $2\mathbf{a} + 6\mathbf{b}$, where $\mathbf{a}$ and $\mathbf{b}$ are non-zero and non-parallel. Show that A, B, C are collinear and find $AC : CB$. **(25 marks)**

17. $ABCDEF$ is a regular hexagon with $\overrightarrow{AB} = \mathbf{a}$ and $\overrightarrow{BC} = \mathbf{b}$. Express $\overrightarrow{CD}$, $\overrightarrow{DE}$, $\overrightarrow{AC}$, $\overrightarrow{AD}$ and $\overrightarrow{AE}$ in terms of $\mathbf{a}$ and $\mathbf{b}$. **(25 marks)**

18. Find the resolved part (component) of $3\mathbf{i} + 4\mathbf{j}$ in the direction of $\mathbf{i} + \mathbf{j}$. Find the unit vectors in the Oxy-plane perpendicular to $3\mathbf{i} + 4\mathbf{j}$. **(25 marks)**

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19. $\mathbf{a}$ and $\mathbf{b}$ are non-zero vectors with $|\mathbf{a} + 2\mathbf{b}| = |\mathbf{a} - 2\mathbf{b}|$. Find the angle between $\mathbf{a}$ and $\mathbf{b}$. If further $|\mathbf{a}| = 3$ and $|\mathbf{b}| = 2$, find $|\mathbf{a} + \mathbf{b}|$. **(25 marks)**

20. Using only the properties $\mathbf{a} \times \mathbf{a} = \mathbf{0}$, $\mathbf{a} \times \mathbf{b} = -\mathbf{b} \times \mathbf{a}$ and the distributive law, show that $(\mathbf{a} + \mathbf{b}) \times (\mathbf{a} - \mathbf{b}) = 2\,(\mathbf{b} \times \mathbf{a})$. Verify this for $\mathbf{a} = \mathbf{i}$, $\mathbf{b} = \mathbf{j}$. **(25 marks)**

21. The greatest and least resultants of two forces acting at a point are 17 N and 7 N. Find the forces, and their resultant when they act at right angles. The resultant of forces $2P$ and $3P$ is $\sqrt{19}\,P$; find the angle between them. **(25 marks)**

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22. Forces P and $2P$ act at a point at an angle of $120°$. Show that their resultant is perpendicular to the force P, and find its magnitude. **(25 marks)**

23. Forces P, $2P$ and $3P$ act at a point in directions making angles $0°$, $120°$ and $240°$ respectively with Ox. Find the magnitude of their resultant and the angle it makes with Ox. **(25 marks)**

24. Let $\mathbf{a} = \mathbf{i} - 2\mathbf{j}$ and $\mathbf{b} = -3\mathbf{i} + \mathbf{j}$. Find the angle between $\mathbf{a}$ and $\mathbf{b}$. Find the scalar λ for which $\mathbf{a} + \lambda\mathbf{b}$ is parallel to $-\mathbf{i} - 3\mathbf{j}$. **(25 marks)**

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25. $|\mathbf{a}| = 2$, $|\mathbf{b}| = 3$ and $\mathbf{a} \cdot \mathbf{b} = 3$. Find the angle between $\mathbf{a}$ and $\mathbf{b}$, the value of $|\mathbf{a} + \mathbf{b}|$, and the value of λ for which $\mathbf{a} + \lambda\mathbf{b}$ is perpendicular to $\mathbf{a}$. **(25 marks)**

26. The vertices A, B, C of a triangle have position vectors $\mathbf{a}, \mathbf{b}, \mathbf{c}$. Show that the point G with position vector $\frac{1}{3}(\mathbf{a}+\mathbf{b}+\mathbf{c})$ lies on each median of the triangle and divides each median in the ratio $2 : 1$. **(25 marks)**

27. Two forces P and Q act at a point and have resultant R. When P is doubled, keeping its direction, the new resultant is perpendicular to Q. Show that $R = P$, and that the magnitude of the new resultant is $\sqrt{4P^2 - Q^2}$. **(25 marks)**

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28. The resultant of two forces P and Q acting at a point is perpendicular to P and equal to P in magnitude. Find Q in terms of P, and the angle between the two forces. **(25 marks)**

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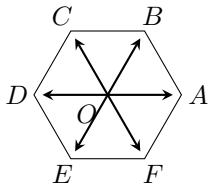
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29. O is the centre of a regular hexagon $ABCDEF$. Forces of magnitudes 2, 7, P, Q, 3, 13 newtons act at O along $\overrightarrow{OA}, \overrightarrow{OB}, \overrightarrow{OC}, \overrightarrow{OD}, \overrightarrow{OE}, \overrightarrow{OF}$ respectively, and the particle at O is in equilibrium. Find P and Q.



(25 marks)

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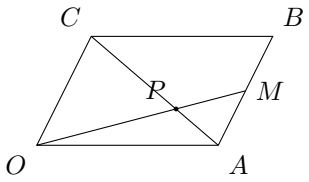
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30. $OABC$ is a parallelogram with $\overrightarrow{OA} = \mathbf{a}$ and $\overrightarrow{OC} = \mathbf{c}$. M is the midpoint of AB and OM meets AC at P. Express $\overrightarrow{OP}$ in terms of $\mathbf{a}$ and $\mathbf{c}$, and show that $AP : PC = 1 : 2$.



(25 marks)

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PART B

Answer **five** questions only, in the answer book provided.

31. **(150 marks)**

(a) $ABCDEF$ is a regular hexagon. Given that $\overrightarrow{AB} = \mathbf{a}$ and $\overrightarrow{BC} = \mathbf{b}$, express each of $\overrightarrow{CD}$, $\overrightarrow{DE}$, $\overrightarrow{EF}$, $\overrightarrow{FA}$, $\overrightarrow{AC}$, $\overrightarrow{AD}$, $\overrightarrow{AE}$ and $\overrightarrow{AF}$ in terms of $\mathbf{a}$ and $\mathbf{b}$.

(b) Prove, using vectors, that the line joining the midpoints of two sides of a triangle is parallel to the third side and half its length.

(c) P, Q, R, S are the midpoints of the sides AB, BC, CD, DA of a quadrilateral $ABCD$. Prove that $PQRS$ is a parallelogram.

(d) Prove, using vectors, that the diagonals of a parallelogram bisect each other.

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32. **(150 marks)**

(a) Let $\mathbf{a}$ and $\mathbf{b}$ be non-zero, non-parallel vectors. Prove that if $\lambda\mathbf{a} + \mu\mathbf{b} = \mathbf{0}$, where $\lambda, \mu \in \mathbb{R}$, then $\lambda = 0$ and $\mu = 0$.

(b) The points A, B, C have position vectors $\mathbf{a} + 2\mathbf{b}$, $3\mathbf{a} - \mathbf{b}$ and $\lambda\mathbf{a} + 5\mathbf{b}$. Find λ if A, B, C are collinear.

(c) Show that the position vector of the point dividing AB internally in the ratio $m : n$ is $\dfrac{n\mathbf{a} + m\mathbf{b}}{m + n}$.

(d) Points A and B have position vectors $\mathbf{a}$ and $\mathbf{b}$. Show that forces represented by $\lambda\overrightarrow{OA}$ and $\mu\overrightarrow{OB}$ have a resultant represented by $(\lambda + \mu)\overrightarrow{OC}$, where C is the point on AB with $AC : CB = \mu : \lambda$.

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33. **(150 marks)**

(a) The points A, B, C have position vectors $2\mathbf{i} + \mathbf{j}$, $5\mathbf{i} + 5\mathbf{j}$ and $9\mathbf{i} + 2\mathbf{j}$. Find $\overrightarrow{AB}$ and $\overrightarrow{BC}$, and show that the triangle ABC is right-angled and isosceles. Find its area and the position vector of D such that $ABCD$ is a square.

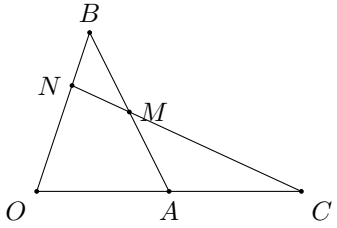
(b) Let $\mathbf{a} = \mathbf{i} + 2\mathbf{j}$ and $\mathbf{b} = 3\mathbf{i} - \mathbf{j}$. Find the cosine of the angle between $\mathbf{a}$ and $\mathbf{b}$. Express $\mathbf{a}$ in the form $\lambda\mathbf{b} + \mathbf{c}$, where $\mathbf{c}$ is perpendicular to $\mathbf{b}$.

(c) Prove that $|\mathbf{a} + \mathbf{b}|^2 + |\mathbf{a} - \mathbf{b}|^2 = 2\left(|\mathbf{a}|^2 + |\mathbf{b}|^2\right)$, and interpret this result for a parallelogram.

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34. **(150 marks)**

(a) In a triangle OAB, $\overrightarrow{OA} = \mathbf{a}$ and $\overrightarrow{OB} = \mathbf{b}$. M is the midpoint of AB, and C is the point on OA produced such that $\overrightarrow{OC} = 2\overrightarrow{OA}$. The line CM produced meets OB at N.



(i) Express $\overrightarrow{OM}$ and $\overrightarrow{CM}$ in terms of $\mathbf{a}$ and $\mathbf{b}$.

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(ii) Show that $\overrightarrow{ON} = \left(2 - \frac{3}{2}\lambda\right)\mathbf{a} + \frac{1}{2}\lambda\mathbf{b}$ for some scalar λ.

(iii) Hence show that $ON : NB = 2 : 1$.

(iv) The line through M parallel to OB meets BC at P. Express $\overrightarrow{MP}$ in terms of $\mathbf{b}$.

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35. **(150 marks)**

(a) $OABC$ is a parallelogram with $\overrightarrow{OA} = \mathbf{a}$ and $\overrightarrow{OC} = \mathbf{c}$. D is the midpoint of AB and E is the midpoint of BC. The lines OD and AE meet at F.

(i) Show that $\overrightarrow{OF} = \lambda\left(\mathbf{a} + \frac{1}{2}\mathbf{c}\right)$ and $\overrightarrow{AF} = \mu\left(\mathbf{c} - \frac{1}{2}\mathbf{a}\right)$ for scalars λ, μ.

(ii) By expressing $\overrightarrow{OF}$ in two ways, find λ and μ, and hence $OF : FD$ and $AF : FE$.

(b) In a triangle ABC, D divides BC in the ratio $1 : 2$ and E is the midpoint of AD. BE produced meets AC at F. Using position vectors relative to A, find $AF : FC$.

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36. **(150 marks)**

(a) In a triangle OAB, $\overrightarrow{OA} = \mathbf{a}$, $\overrightarrow{OB} = \mathbf{b}$. P is on OA with $OP : PA = 1 : 2$ and Q is on OB with $OQ : QB = 3 : 1$. The lines AQ and BP meet at R. Find $\overrightarrow{OR}$ in terms of $\mathbf{a}$ and $\mathbf{b}$, and find the ratios $AR : RQ$ and $BR : RP$.

(b) Using vectors, show that the line joining a vertex of a parallelogram to the midpoint of an opposite side trisects a diagonal.

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37. **(150 marks)**

(a) The position vectors of A and B relative to the origin O are $\mathbf{i}+3\mathbf{j}$ and $\alpha\mathbf{i}-\mathbf{j}$, and OA is perpendicular to OB. Show that $\alpha = 3$. C has position vector $\frac{3}{2}\mathbf{i} + 2\mathbf{j}$. Show that A, B, C are collinear and find $AC : CB$. D is the point on OC such that OD is perpendicular to AD. Show that the position vector of D is $\frac{3}{5}(3\mathbf{i} + 4\mathbf{j})$.

(b) AB is a diameter of a circle with centre O and P is any other point on the circle. Using the scalar product, prove that $A\hat{P}B = 90°$.

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38. **(150 marks)**

(a) O, A, B, C are points such that $OA \perp BC$ and $OB \perp CA$. Using the scalar product, prove that $OC \perp AB$. Deduce that the altitudes of a triangle are concurrent.

(b) Using the scalar product, prove the cosine rule for a triangle.

(c) For $\mathbf{a} = a_1\mathbf{i}+a_2\mathbf{j}$ and $\mathbf{b} = b_1\mathbf{i}+b_2\mathbf{j}$, show that $\mathbf{a}\times\mathbf{b} = (a_1b_2-a_2b_1)\mathbf{k}$, and verify that $\mathbf{a}\times\mathbf{b} = -\mathbf{b}\times\mathbf{a}$.

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39. **(150 marks)**

(a) Resolve a force of 20 N into two components making angles of 30° and 45° with it, on opposite sides of it.

(b) Forces of $1, 2, 3, 4$ newtons act at a point in directions making $0°, 60°, 120°, 180°$ respectively with Ox. Find the magnitude of the resultant and the angle it makes with Ox.

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(c) Forces of 2 N, 3 N and 4 N act at a point in directions making angles of 120° with one another. Find the magnitude of their resultant.

(d) A particle is acted on by forces of 5 N along Ox, 4 N along Oy, and $3\sqrt{2}$ N in the direction making 225° with Ox. Find the additional force needed to keep the particle in equilibrium.

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40. **(150 marks)**

(a) Forces $P\mathbf{i} + 2\mathbf{j}$, $3\mathbf{i} + Q\mathbf{j}$ and $-4\mathbf{i} - 5\mathbf{j}$ act at a point. Their resultant has magnitude $2\sqrt{2}$ and is parallel to $\mathbf{i} + \mathbf{j}$. Find all possible pairs of values of P and Q.

(b) The resultant of forces of 7 N and 8 N acting at a point is 13 N. Find the angle between them.

(c) Forces of 4 N, 5 N and 6 N act at a point and are in equilibrium. Find the cosine of the angle between the 4 N and 5 N forces.

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41. **(150 marks)**

(a) State the parallelogram law of forces. Forces P and Q act at a point at an angle α. Show that the magnitude R of their resultant satisfies $R^2 = P^2 + Q^2 + 2PQ\cos\alpha$, and that it makes an angle ϕ with P where $\tan\phi = \dfrac{Q\sin\alpha}{P + Q\cos\alpha}$.

(b) With $P > Q$, show that $\dfrac{P-Q}{P+Q} = \dfrac{\tan\left(\frac{\alpha}{2} - \phi\right)}{\tan\frac{\alpha}{2}}$. If P and Q are interchanged, each acting along the other's original line, show that the resultant turns through an angle θ where $\tan\frac{\theta}{2} = \frac{P-Q}{P+Q}\tan\frac{\alpha}{2}$.

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42. **(150 marks)**

(a) Forces P and Q at angle α have resultant R. When Q is reversed the resultant is R'. Show that $R^2 + R'^2 = 2(P^2 + Q^2)$. If $P = Q$ and $R = 2R'$, find $\cos\alpha$.

(b) The resultant of two forces P and Q is R. If Q is doubled, R is doubled; if Q is reversed, R is again doubled. Show that $P : Q : R = \sqrt{2} : \sqrt{3} : \sqrt{2}$.

(c) Two forces P and Q act along OA and OB. Show that their resultant bisects the angle $A\hat{O}B$ if and only if $P = Q$.

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43. **(150 marks)**

(a) $ABCDEF$ is a regular hexagon. Forces represented by $\overrightarrow{AB}, \overrightarrow{AC}, \overrightarrow{AD}, \overrightarrow{AE}, \overrightarrow{AF}$ act at A. Show that their resultant is represented by $3\overrightarrow{AD}$.

(b) G is the centroid of a triangle ABC and O is any point. Show that forces represented by $\overrightarrow{OA}, \overrightarrow{OB}, \overrightarrow{OC}$ have resultant represented by $3\overrightarrow{OG}$.

(c) Forces represented by $\overrightarrow{AB}$, $2\overrightarrow{BC}$ and $3\overrightarrow{CA}$ act at a point, where ABC is an equilateral triangle of side a. Find the magnitude of their resultant.

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44. **(150 marks)**

Solve each part by resolving the forces in two perpendicular directions.

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(a) A particle of weight W rests on a smooth plane inclined at 30° to the horizontal. It is held by a light string which makes 30° with the line of greatest slope, lying above the plane. Find the tension in the string and the reaction of the plane.

(b) A particle of weight W is held at rest on a smooth plane inclined at α to the horizontal by a horizontal force P. Find P and the reaction.

(c) A particle of weight W hangs from two light strings of lengths $3a$ and $4a$ whose other ends are fixed at two points $5a$ apart on the same horizontal level. Find the tensions in the strings.

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45. **(150 marks)**

Solve each part by resolving the forces in two perpendicular directions.

(a) A particle of weight W hangs on a light string. It is pulled aside so that the string makes an angle θ with the vertical. Find the pulling force and the tension when the pulling force is (i) horizontal, (ii) perpendicular to the string. Show that (ii) gives the smaller pulling force.

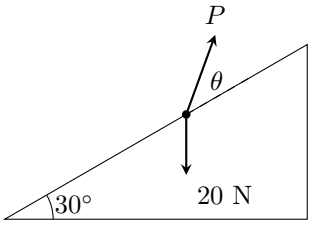
(b) A smooth ring of weight W is threaded on a light string of length $2l$. The ends of the string are fixed at two points $2d$ apart on the same horizontal level ($d < l$). Find the tension in the string.

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46. **(150 marks)**

Solve each part by resolving the forces in two perpendicular directions.

(a) A particle of weight 20 N rests on a smooth plane inclined at 30° to the horizontal. It is held by a force P acting at an angle θ above the line of greatest slope, as shown.



Show that $P = 10 \sec\theta$ and find the reaction R of the plane. Deduce the range of values of θ for which the particle stays in contact with the plane.

(b) Forces of 8 N and 15 N act at a point at right angles to each other. Find the magnitude and direction of the force which keeps the point in equilibrium.

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