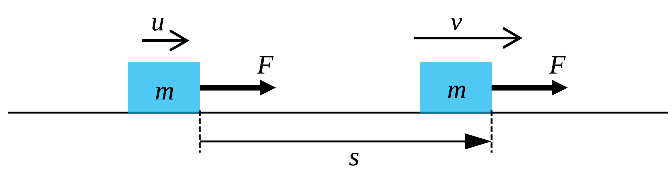
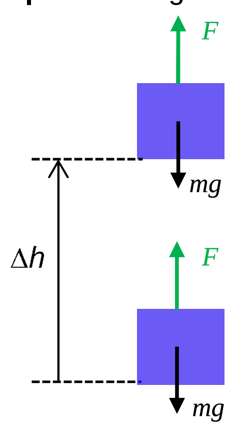
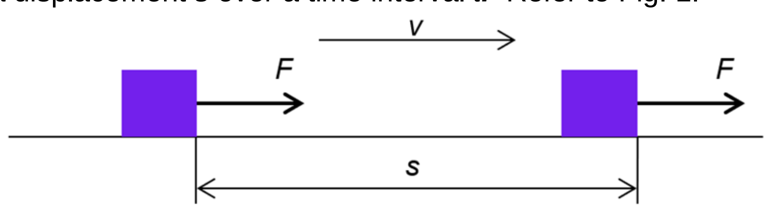
JURONG PIONEER JUNIOR COLLEGE
9478 H2 PHYSICS

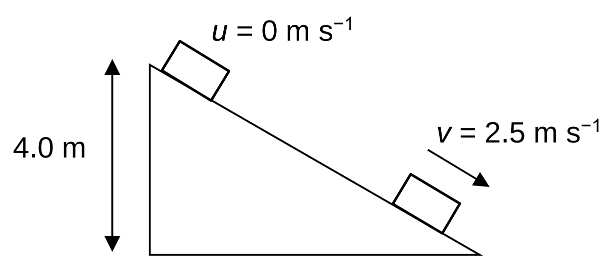
ENERGY AND FIELDS TUTORIAL SOLUTIONS

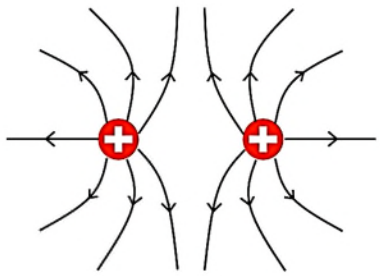
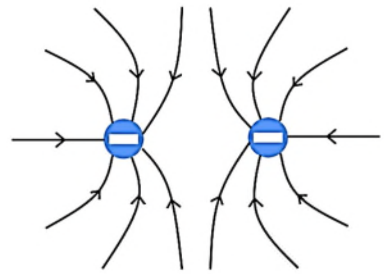
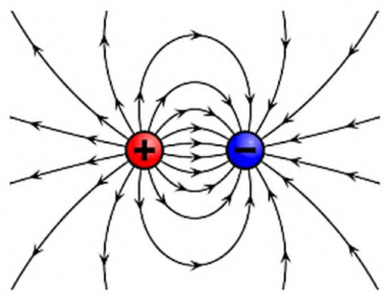
Qn.	Solution
Self-Check Questions	
S1	The work done by a force on an object is defined as the product of the force and the displacement of the object in the direction of the force.
S2	• Kinetic energy is a scalar quantity that represents the energy associated with the body due to its motion. • Consider an object of mass *m* on a horizontal frictionless surface. A constant force *F* acts on the object, causing it to accelerate from an initial velocity of *u* to a final velocity *v*, covering a displacement of *s*.  Fig. 10: Object accelerating under constant force • **Work done by force *F*** on the object is **transferred to** the object as its **kinetic energy** (law of conservation of energy). An equation for kinetic energy would need to link work done to the velocity of the object. This can be done by applying the kinematics equations. • Work done by force *F* on the object, $W = Fs$ - - - (1) • Since the surface is frictionless, *F* is the net force acting on the mass. Hence *F* in equation (1) can be replaced by $F = ma$. $W = Fs$ $W = (ma)s$ - - - (2) • Since the net force is constant, **acceleration *a* is constant,** and the kinematics equation of motion applies. $v^2 = u^2 + 2as$ $a = \frac{1}{2s}(v^2 - u^2)$ - - - (3) • Substitute (3) into (2), work done by force *F* is:

Qn.	Solution
	$W = (ma)s$ $W = m\left[\frac{1}{2s}(v^2 - u^2)\right]s$ $W = \frac{1}{2}m(v^2 - u^2)$ $W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ • **Work-Energy Theorem** states that: The ***net work done*** by external forces acting on an object (or a system) is equal to the object's (or system's) ***change in kinetic energy***. work done by net force, $W = (E_k)_{final} - (E_k)_{initial}$ $W = \Delta E_k$ • If the object accelerates from rest to a final velocity of v, all the work done is transferred into the object's kinetic energy E_k: $\boxed{E_k = \frac{1}{2}mv^2}$
S3	• Near the Earth's surface, the gravitational field is **uniform** and the acceleration of free fall g is taken to be constant. • Consider an object of mass m lifted by a constant force F, vertically upwards at **constant speed** from ground level to a height Δh .  Fig. 11: object rising at constant velocity • At constant speed, the applied force must **balance** the weight of object, $F = mg$ • Since the object's velocity is constant, its kinetic energy is also **constant**.

Qn.	Solution
	• Hence work done by the applied force F on the object is transferred to the object to increase its gravitational potential energy (law of conservation of energy). • Work done by F is $W = Fs$ $W = mg \times \Delta h$ $\boxed{\Delta E_{\text{p}} = mg\Delta h}$
S4	Efficiency of a practical device is a measure of the useful energy output to the total energy input. $\boxed{\eta = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%}$
S5	The gravitational field strength at a point in space is the gravitational force experienced per unit mass on a mass at that point. $g = \frac{F_{\text{G}}}{m} = \frac{GM}{r^2}$
S6	The electric field strength at a point is the electric force exerted per unit charge on a positive charge placed at that point. $E = \frac{F_{\text{E}}}{q} = \frac{Q}{4\pi\varepsilon_0 r^2}$
S7	Power is defined as the rate at which work is done. • Consider a constant force F being applied on an object such that F cancels other forces on the object, resulting in a net force of zero on the object. Under the influence of this force F, the object moves at a constant velocity of v and cover a displacement s over a time interval ***t.*** Refer to Fig. 1.  Fig. 1: Work done by a constant force moving object at constant velocity • Work done by the force F, $W = Fs$ • Power delivered by the force F,

Qn.	Solution
	$P=\dfrac{W}{t}$ $P=\dfrac{Fs}{t}$ $P=F\left(\dfrac{s}{t}\right)$ $P=Fv$

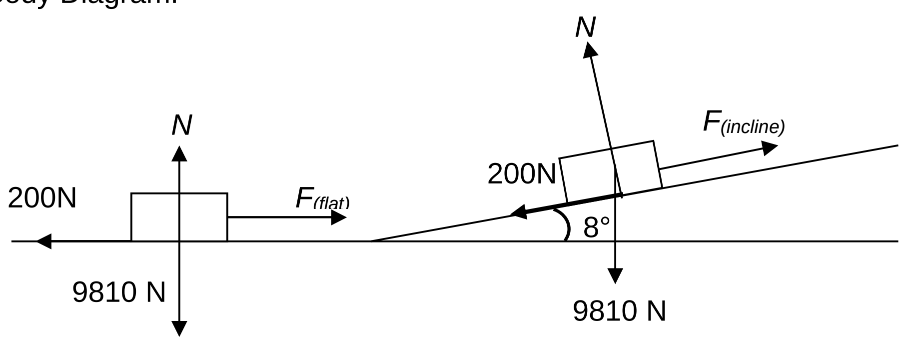
Qn.	Solution
Self-Practice Questions	
P1(a)	$W=Fs\cos\theta$ $=(200)(10)\cos 30^{\circ}$ $=1732$ ≈ 1700 J
P1(b)	No work is done as the force exerted is perpendicular to the direction of motion of the satellite.
P1(c)	$W=-Fs\cos\theta$ $=-(800)(0.5)\cos 180^{\circ}$ $=400$ J
P2	 Using the principle of conservation of energy, Loss of gravitational PE = Gain of KE + thermal energy thermal energy $=mgh-\dfrac{1}{2}mv^2$ $=(20)(9.81)(4.0)-\dfrac{1}{2}(20)(2.5)^2$ $=722$ J

Qn.	Solution
P3(a)	 
P3(b)	
P4	Average power, $P = \dfrac{\text{total W}}{\text{total time}}$ $= \dfrac{Fs}{t}$ $= \dfrac{(8000)(20)}{4.0}$ $= 40000 \text{ W}$ $= 40 \text{ kW}$
P5	At constant speed, driving force F = frictional force f $P = Fv = fv = kv^2 \times v = kv^3$ (where k is a constant) $\dfrac{P_2}{P_1} = \left(\dfrac{v_2}{v_1}\right)^3$ $P_2 = \left(\dfrac{40}{20}\right)^3 (26) = 208 \text{ kW}$

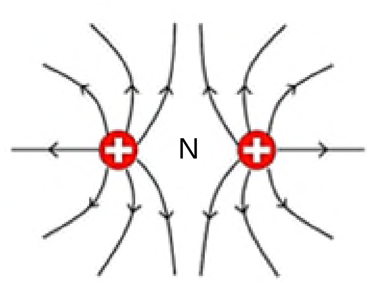
Qn.	Solution
Discussion Questions	
1	Work done by the spring during the reduction in length from l_1 to l_2 = area under graph during reduction in length from l_1 to l_2 = area MNQP
2(a)	The kinetic energy store of the bungee jumper at the start and the end of the jump is zero. Using the principle of conservation of energy, Decrease in GPE = gain in EPE $60.0 \times 9.81 \times 31.0 = \frac{1}{2} \times k \times (31.0 - 12.0)^2$ $k = 101.1$ $\approx 101 \text{ N m}^{-1}$
2(b)	When the jumper reaches the lowest point, tension in the cord, $T = kx$ $= 101.1 \times 19.0$ $= 1920.9$ $\approx 1921 \text{ N}$ Taking upwards as positive, $ma = T - mg$ $60.0a = 1920.9 - (60.0)(9.81)$ $a = 22.21$ $\approx 22.2 \text{ m s}^{-2}$
3(a)	Length of ramp $= \sqrt{10.0^2 + 24.0^2} = 26.0$ m By Conservation of Energy, Work done on crate + Loss in GPE = Gain in KE $(40.0 \times 26.0) + (15.0)(9.81)(10.0) = \frac{1}{2}(15.0)v^2$ $v = 18.299$ $\approx 18.3 \text{ m s}^{-1}$

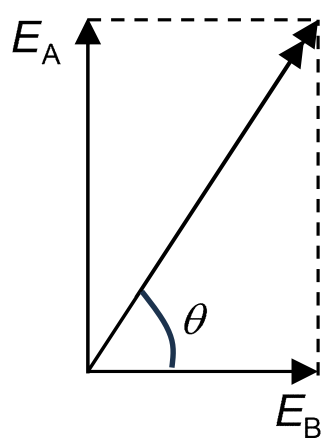
<table>
<tr><th>Qn.</th><th>Solution</th></tr>
<tr><td>3(b)</td><td>By Conservation of Energy,
Gain in $PE_{elastic}$ + Work done against friction = Loss in KE
$\frac{1}{2}(200)x^2 + 100x = \frac{1}{2}(15.0)(18.3)^2$
$x = 4.5359$
≈ 4.54 m</td></tr>
<tr><td>4(a)(i)</td><td>Loss in GPE
$= mgh$
$= 0.400 \times 9.81 \times 0.200$
$= 0.7848$
≈ 0.785 J</td></tr>
<tr><td>4(a)(ii)</td><td>At equilibrium,
$kx = mg$
$0.200k = 0.400 \times 9.81$
$k = 19.62 \text{ N m}^{-1}$

Gain in EPE
$= \frac{1}{2}kx^2$
$= \frac{1}{2}(19.62)(0.200)^2$
$= 0.3924$
≈ 0.392 J</td></tr>
<tr><td>4(b)</td><td>
<table>
<tr><th></th><th>gravitational potential energy / J</th><th>elastic potential energy / J</th><th>kinetic energy / J</th><th>total energy / J</th></tr>
<tr><td>0.200m below point X</td><td>0</td><td>1.57</td><td>0</td><td>1.57</td></tr>
<tr><td>point X</td><td>0.785</td><td>0.392</td><td>0.392</td><td>1.57</td></tr>
<tr><td>0.200m above point X</td><td>1.57</td><td>0</td><td>0</td><td>1.57</td></tr>
</table>
</td></tr>
<tr><td>5(a)</td><td>GPE lost by bird = KE gained by bird
$m(9.81)h = \frac{1}{2}m(9.0)^2$
$h = 4.13$ m</td></tr>
</table>

Qn.	Solution
5(b)(i)	KE at P $=\frac{1}{2}\left(120\times10^{-3}\right)\left(13.0\right)^{2}$ $=10.14$ $\approx 10.1\ \text{m s}^{-1}$
5(b)(ii)	Total gain in GPE $=\left(120\times10^{-3}\right)\left(9.81\right)\left(7.5\right)$ $=8.829$ $\approx 8.83\ \text{m s}^{-1}$
5(b)(iii)	GPE gained by bird = KE lost by bird (Taking GPE = 0 at P) *mgh* – 0 = KE at P – KE at nest 8.83 = 10.1 – KE at nest KE at nest = 1.27 J
5(b)(iv)	KE of bird as it reaches its nest $\frac{1}{2}\left(120\times10^{-3}\right)v^{2}=1.27$ $v=4.60\ \text{m s}^{-1}$
6(a)	Free Body Diagram:  Motion on flat ground: Since speed is constant, acceleration = 0 m s^{-2} Hence resultant force on car = 0 N If *F* is engine force, $F_{\text{flat}}-200=0$ $F_{\text{flat}}=200\ \text{N}$

Qn.	Solution
	$P_{\text{flat}} = F_{\text{flat}} \times v$ $= 200 \times 20$ $= 4000$ $= 4.0 \times 10^3$ W
6(b)	Motion up an incline: $F_{\text{incline}} - 200 - (1000)(9.81)\sin 8^\circ = 0$ $F_{\text{incline}} = 200 + (1000)(9.81)\sin 8^\circ$ $= 1565$ N $P_{\text{incline}} = F_{\text{incline}} \times v$ $= 1565 \times 20$ $= 31300$ $\approx 3.1 \times 10^4$ W
7(a)	Work done against gravity $= mg\Delta h$ $= 50.0 \times 9.81 \times 8.00$ $= 3924$ $\approx 3.92 \times 10^3$ J
7(b)	Average power output = work done / time $= \dfrac{3924}{20}$ $= 196.2$ ≈ 196 W
7(c)	$\text{efficiency} = \dfrac{\text{power output}}{\text{power input}}$ $\text{power input} = \dfrac{196.2}{0.8}$ $= 245 \text{ W } (3 \text{ s.f.})$
8(a)	$g = \dfrac{(6.67 \times 10^{-11})(30)}{25}$ $\approx 8.0 \times 10^{-11}$ N kg^{-1}

Qn.	Solution
8(b)	
8(c)(i)	Magnitude decreases 3 times but direction remains unchanged.
8(c)(ii)	Magnitude decreases 4 times but direction remains unchanged.
8(c)(iii)	Magnitude and direction remain unchanged.
9	Using $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$, Electric field strength due to $+2.0\mu$C $E_1 = \dfrac{2.0\times10^{-6}}{4\pi\left(8.85\times10^{-12}\right)(0.50)^2}$ $= 7.193\times10^4$ N C^{-1} (rightwards) Electric field strength due to -2.0μC $E_2 = \dfrac{2.0\times10^{-6}}{4\pi\left(8.85\times10^{-12}\right)(0.50)^2}$ $= 7.193\times10^4$ N C^{-1} (rightwards) Resultant electric field strength at midpoint $E_{\text{resultant}} = E_1 + E_2$ $= 2\left(7.193\times10^4\right)$ $= 1.439\times10^5$ $\approx 1.44\times10^5$ N C^{-1} (rightwards)
10(a)	

Qn.	Solution
10(b)(i)	Using $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$, Electric field strength at P due to charge A $E_A = \dfrac{2.0\times10^{-9}}{4\pi\left(8.85\times10^{-12}\right)\left(120\times10^{-3}\right)^2}$ $= 1249$ $\approx 1.25\times10^3$ N C^{-1} (vertically upwards)
10(b)(ii)	Electric field strength at P due to charge B $E_B = \dfrac{3.0\times10^{-9}}{4\pi\left(8.85\times10^{-12}\right)\left(160\times10^{-3}\right)^2}$ $= 1054$ $\approx 1.05\times10^3$ N C^{-1} (rightwards)
10(b)(iii)	 Magnitude of resultant electric field strength at P $E_{resultant} = \sqrt{(1249)^2 + (1054)^2}$ $= 1634$ $= 1.63\times10^3$ N C^{-1}

Qn.	Solution
	$\theta = \tan^{-1}\left(\frac{E_A}{E_B}\right)$ $= \tan^{-1}\left(\frac{1249}{1054}\right)$ $= 49.8^\circ$ Resultant electric field strength at P is 1.63×10^3 N C^{-1} at 49.8° above horizontal as shown in the diagram.
11(a)(i)	Extension = 73 – 41 = 32 m
11(a)(ii)	From the graph, when x = 32 m, F = 3350 N $\therefore$ Elastic PE $= \frac{1}{2}Fx$ $= \frac{1}{2}(3350)(32)$ $= 53600$ $\approx 5.4 \times 10^4$ J
11(b)(i)	<table><tr><td></td><td>at the top</td><td>after falling 41 m</td><td>after falling 73 m</td></tr><tr><td>GPE / J</td><td>54000</td><td>24000</td><td>0</td></tr><tr><td>EPE / J</td><td>0</td><td>0</td><td>54000</td></tr><tr><td>KE / J</td><td>0</td><td>30000</td><td>0</td></tr></table> GPE at the top $= 75 \times 9.81 \times 73$ $= 53710$ ≈ 54000 J GPE after falling 41 m $= 75 \times 9.81 \times 32$ $= 23544$ ≈ 24000 J
11(b)(ii)1.	At maximum KE, resultant F on man = 0 i.e. weight of man = tension force on man by rope $F = (75)(9.81)$ $= 736$ N

Qn.	Solution
	From the graph, x = 7 m Total distance fallen = 41 + 7 = 48 m
11(b)(ii)2.	At x = 7 m, Elastic PE $=\frac{1}{2}(736)(7)=2576$ J Max KE = Total Energy – EPE – GPE $=53700-2576-(75)(9.81)(73-48)$ $=32730$ $\approx 3.3\times10^4$ J (33 kJ)
11(b)(iii)