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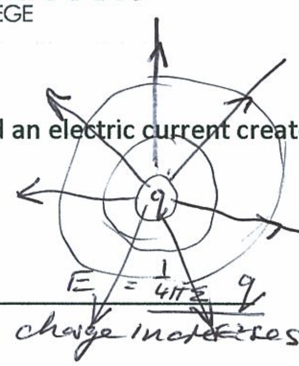
04 SAT Light and Matter



1. In the 17 30's Faraday investigated changing magnetic fields and observed an electric current created in a conductor.

+3ℓ Describe with the support of a diagram.

a) What is present in the region surrounding a charged particle?

An electric field whose strength decreases $E = \frac{1}{4\pi\varepsilon} \frac{q}{r^2}$ (2)

at the rate $\propto \frac{1}{r^2}$ as the distance r from the charge increases

b) What must be present associated with the induced current?

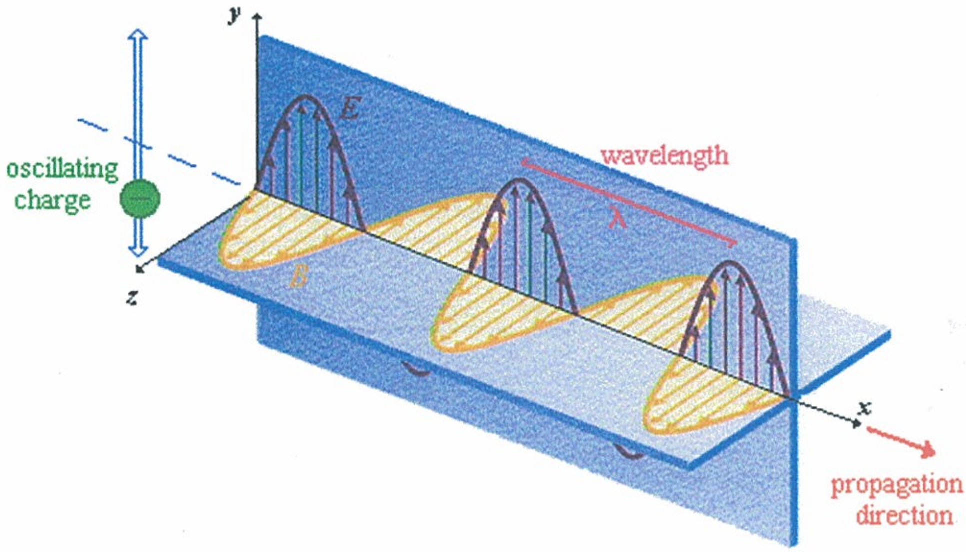
a changing electric field (1)

c) Maxwell in thinking about Faradays findings made an assumption about the symmetry of nature. What did he assume?

+.1ℓ If a changing B field creates a changing E field it could be anticipated that a changing E field could create a changing B field. (1)

2. In the 17th century light was observed to travel in straight lines and particle theory was consistent with the measurements of reflection and refraction. Calculations of the speed of light showed it travelled at 3×10^8 ms^{-1} ~~too~~ These ~~theories~~ observations had to be reinterpreted ~~in the~~ as understanding of e-m radiation developed.

a) Refer to the diagram provided, to explain the creation of an electro-magnetic wave.



1. When a changing potential difference is applied to a conductor the electrons experience a force which causes them to accelerate

(4)

towards the positive potential. An ~~moving~~ accelerating charge creates a changing electric field ✓
The electric field strength is at a maximum as the electrons change direction as the ΔV changes
A changing electric field creates a changing magnetic field ✓ at 90° to the E field. The B field strength is a max^m when the E field is a max^m
The E field is produced in the same plane as the conducting wire and it propogates away from the wire at $3 \times 10^8 ms^{-1}$ ✓ So the direction of ✓ propogation, B & E fields are mutually perpendicular. 6m

+3l

Mathematical calculations predicted this electro-magnetic wave would propagate at 3×10^8 ms^{-1}. What did this suggest about visible light?

It suggested visible light was an e-m wave rather than a particle, It would show diffraction through & interference ~~to~~ a small gap ✓ (2)

b) Calculate the frequency of radio waves which have a wavelength of 240cm.

$v = f\lambda$ $f = c/\lambda$

+1l $3 \times 10^8 / 2.4$ $f = 1.25 \times 10^8$ Hz (1)

c) Explain why it is possible to improve the reception of an old TV (analogue) by adjusting the orientation of the internal antennae.

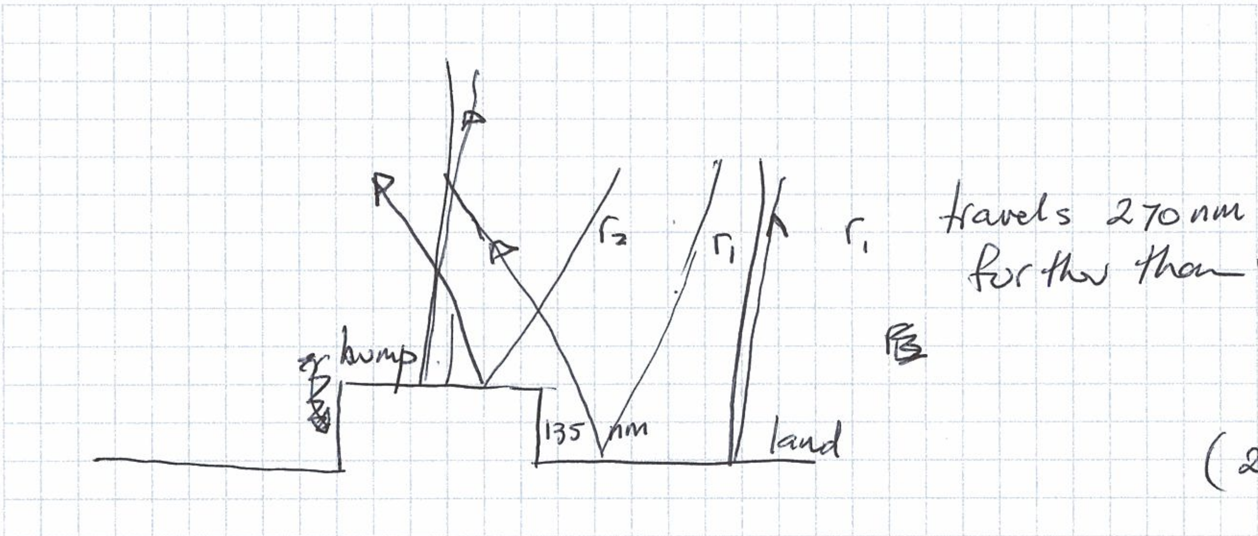
the recieving antennae needs to be in the same orientation as the transmitting antennae to pick up the changing E field. (1)

9

3. A compact Disk player reads the surface using a laser beam. The tracks on a CD contain bumps and lands. As the laser is reflected from these surfaces the signal intensity changes.

Consider a CD where the bumps on the track have a height of 135nm and are read by a laser with wavelength 520 nm, directed ~~almost~~ vertically down on the CD

a) Draw a labelled diagram showing a beam reflecting off a bump and a beam reflecting off the flat. ~~Identify key information~~.



(2)

c) By comparing the path difference between the two beams, with the wavelength of the laser, explain why light reflected from a bump and a flat surface interferes to produce a beam of reduced intensity.

the path difference is 270 nm which is $\frac{270}{520}$ .52 λ. This will cause destructive interference reducing the intensity of the beam. (2)

4. A diathermy machine, used in physiotherapy to hasten the repair of soft tissue damage, generates e-m radiation that gives the effect of deep heat. If the machine generates waves with frequency 15.6MHz

a. What is the wavelength of this electromagnetic wave? $v = f\lambda$

b. To which part of the e-m spectrum does it belong?

$\lambda = c/f$

$= \frac{3 \times 10^8}{15.6 \times 10^6}$

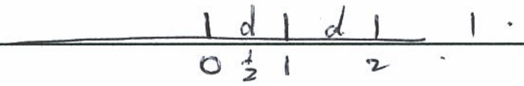
$= 19.2$ m.

radio wave (no need for protection) (2)

(6)

5. In a young's double slit experiment , the double slits are illuminated with light containing 2 wavelengths. One of the wavelengths is 580nm while the other is ~~un~~known. The fourth bright fringe of the 580nm radiation coincides with the sixth dark fringe for the unknown wavelength. Determine the unknown wavelength.

$\lambda_1 = 580\,nm$ $m = 4$ constructive   coincides $m = 5\frac{1}{2}$ λ_2 dark



$d \sin\theta = m\lambda$ ($4 \times 580\times10^{-9}$)

$d \sin\theta = 5\frac{1}{2}\lambda_2$

so $\lambda_2 = \frac{2}{11} \times 4 \times 5.8\times10^{-7}$

$\lambda_2 = 422\,nm$ (3)

6. Find the wavelength of three lines in the spectrum of hydrogen, given that these lines reinforce in the first order at angles of 20.68°, 20.07° and 16.93° from the normal to the grating. Base your calculations on the fact that the mercury ~~green~~ 2nd order line of wavelength 54.1 nm is seen at ~~18.82°~~ 40.2

$d \sin 18.82 = m\,\lambda\, 54.1\times10^{-9}$ ~~assume~~ $m = 2$

$d = \frac{2\times 54.1\times10^{-9}}{\sin 40.2}$

$= 1.676\times10^{-7}$ (Keep sf as using for further calc)

l_1 $1.676\times10^{-7} \sin 20.68 = \lambda_1$

$= 59.2\,nm$

l_2 $1.676\times10^{-7} \sin 20.07 = \lambda_2$

$= 57.6\,nm$ (4)

l_3 $1.676\times10^{-7} \sin 16.93 = \lambda_3$

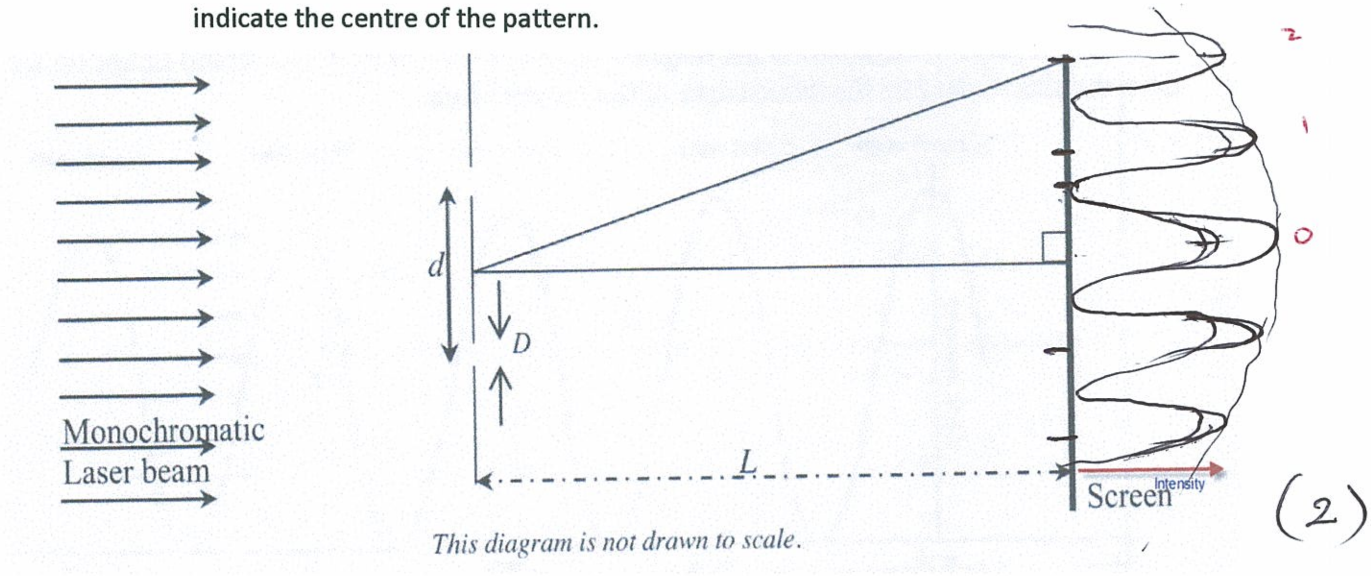
$= 48.8\,nm$

(7)

7. A 5.6 x 1014 Hz laser beam is directed onto two slits as shown below.

   a. Mark on the screen in the diagram below, an indication of the band width(qualitative) for 2 orders above and below the central order.

   b. Using the positions shown from part a sketch an intensity graph along the screen. Clearly indicate the centre of the pattern.



This diagram is not drawn to scale.

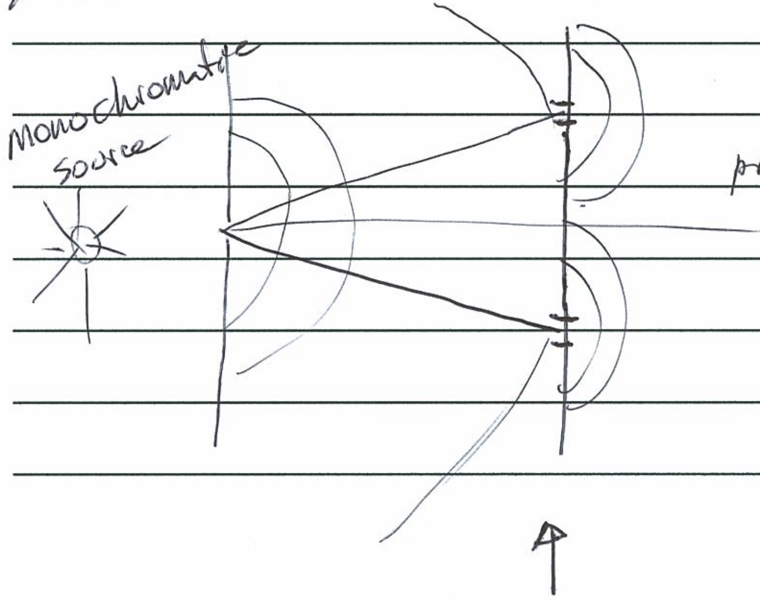
(2)

   c. To produce an interference pattern, the light incident on the slits must be in a constant phase relationship.

      i. Explain the phrase *constant phase relationship*

+2l. beams of e-m radiation of the same frequency, in the same medium maintain the same relationship ie 2 crests propogate out at the same speed so after a time (t) the crests are in the same relative position (2)

      ii. In the diagram above, a coherent light source is from the laser, outline an alternative method for producing coherent light, from a non-coherent source to illuminate the slits.



note 1. monochromatic source produces e-m all of same frequency
2. single medium
3. double slits symmetrical placement from single slit.
4 2 slits now produce coherent em radiation. (3)

diffracted waves will be incident on the double slits at the same time to create coherent light (7)

d. Describe quantitatively how the interference pattern with fringe width of 1.2×10^{-4} m changes if the distance d between the slits is reduced by a third.

$\Delta y = 1.2\times10^{-4}$ m $\Delta y = \frac{\lambda L}{d}$ λ & L held constant

$\Delta y \propto 1/d$

Δy will be 3 times the width

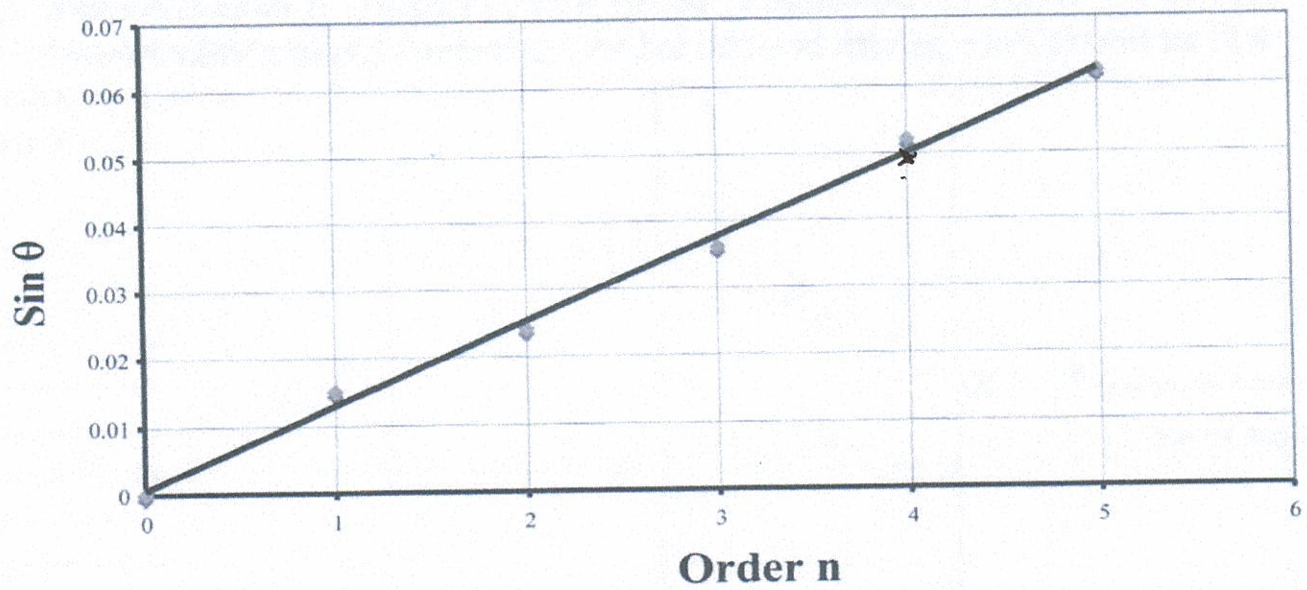
ie $3\times1.2\times10^{-4}$

new $\Delta y = 3.6\times10^{-4}$ m   (1)

+1l

8. The graph below shows the measured angular positions Ø of the interference maxima for a transmission grating, plotted as a function of the order, n of the maximum.

Sin θ V's order of constructive interference for micro waves



Use the graph to determine the wavelength of ~~light~~ e-m radiation given that the grating was 25 lines per mm.

$d = \frac{10^{-3}}{25}$

$= 4\times10^{-5}$ m

sin θ = slope n as line passes through (0,0)

Use pt (4, 0.05) and (0,0) from line ~~slope~~ of best fit.

slope $= \frac{0.05}{4}$

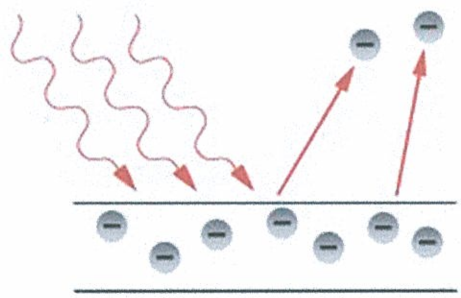
$= 1.25\times10^{-2}$

$d\sin\theta = n\lambda$ use order = n

$\sin\theta = \frac{\lambda}{d} n$ so λ/d corresponds with the slope

$\lambda/d = 1.25\times10^{-2} \times 4\times10^{-5}$

$= 5\times10^{-7}$ M   (4)   (5)



(extended answer question)

9. Describe the characteristics of the photoelectric effect and how the concept of a photon is important in explaining these effects.

define photo electric effect.

note threshhold frequency explain work function

note photons only give up descrete energy hf, so high intensity of low E photon will not cause electrons to be emitted

Above f_0 least strongly held electrons emitted with $K_{max} = hf - W$.

above f_0 increase in intensity does increase number of $\bar{e}$ emitted, but E_{max} is same

characteristics of instant emission

threshold frequency

~~no~~ set E_{max} for given incident photon.

(8)

10. The photoelectric work function for sodium is 2.3eV

    a. Calculate the threshold wavelength of incident light for this metal

    b. Explain whether light of wavelength 580 nm would cause the emission of a photoelectron

    c. Light of wavelength 350nm illuminates the sodium surface: calculate the range of kinetic energies with which electrons are ejected.

a) $W = 2.3eV$

min $E = 1.6\times10^{-19} \times 2.3$ $\quad 3.68\times10^{-19}$ J

$f = \frac{1.6\times10^{-19}\times 2.3}{6.63\times10^{-34}}$ $\quad \lambda = \frac{c}{f} = \frac{3\times10^{8}}{5.55\times10^{14}}$

$= 5.55\times10^{14}$ Hz $\quad \lambda_{min} = 5.405\times10^{-7}$ (Keep accuracy as will be used in further calc)

b) $E = hf$ $\quad c = f\lambda \quad f = c/\lambda$

$= hc/\lambda$

$= 6.63\times10^{-34}\times 3\times10^{8} / 580\times10^{-9}$

$= 3.429\times10^{-19}$ J

$= 2.14$ eV this is insufficient energy to cause an emission as it is less than the work function for sodium.

c) More space

$f = \frac{3\times10^{8}}{3.5\times10^{-7}}$

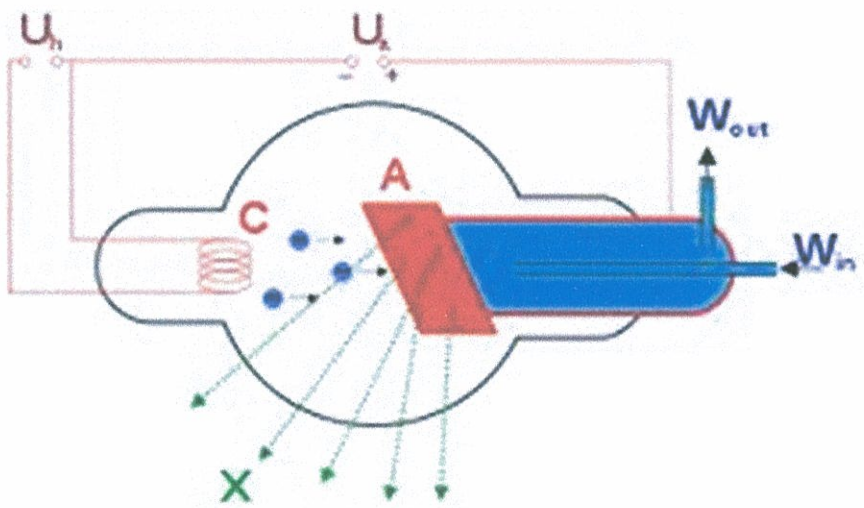
$E_{max} = hf - 3.68\times10^{-19}$

$(5.683 - 3.68)\times10^{-19}$

$= 2.00\times10^{-19}$ J

Range $0 - 2.00\times10^{-19}$ J.

(5)



11. In the x ray tube shown above explain how to
    a. increase the hardness of the X rays produced
    b. Increase the intensity of the X rays

$c = f\lambda$

Increase acce

(a) What acceleration potential is required to produce X rays with max^m hardness of ~~5.20 x10^-11 m~~ 5.77×10^{18} Hz

$f = \frac{3 \times 10^8}{5.2 \times 10^{-11}} = 5.77 \times 10^{18}$ Hz

Max^m $E = 6.63 \times 10^{-34} \times 5.77 \times 10^{18} = 3.826 \times 10^{-15}$ J

$\Delta V = \frac{E}{q}$

$= 2.39 \times 10^{4}$ V

(2)

12. a. Calculate the DeBroglie wavelength of an electron moving with a speed of $3 \times 10^5 ms^{-1}$. $3.00 \times 10^5 ms^{-1}$
    b. Explain how would you detect this wave length?

$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 3 \times 10^5}$ $\lambda = 2 \times 10^{-19}$ m (1sf)

$= 2.43 \times 10^{-9}$ m

A diffraction grating with ~~shoot~~ ~~6~~ 6100 lines/mm will not create ~~not~~ an interference pattern

as $d = 10^{-6}$ will not create sufficient diffraction

So need to use a regular crystal where the atomic spacing is in the order of 10^{-11}

(2)

13. **Derive an expression relating kinetic energy to momentum for a particle. Hence sketch a graph of kinetic energy versus momentum**

$p = mv$

$E_k = \frac{1}{2} mv^2$

$2mE_k = m^2v^2$

$E_k = \frac{p^2}{2m}$

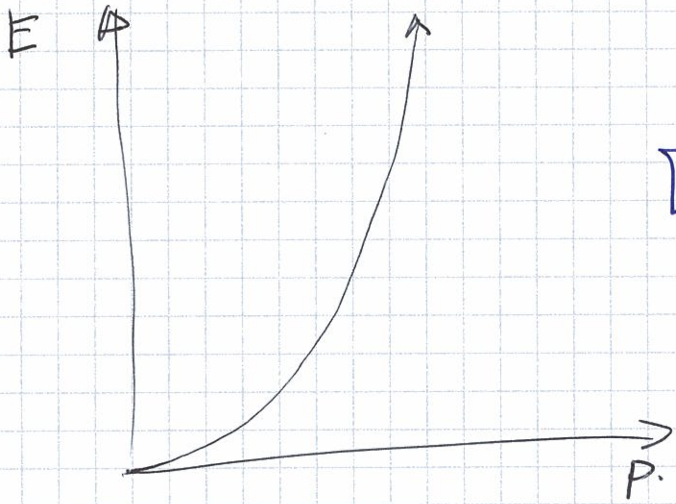
[poor question]

assuming m is a constant (which is not actually the case)

$E_k \propto p^2$

and when $E_k = 0$ $p = 0$

[note there is a physical limit to $E_{K(max)}$ and mass is not a constant]



(4)

59

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