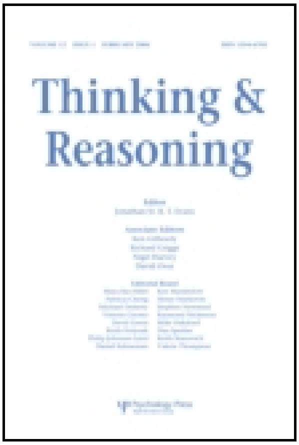

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Time of day effects on problem solving: When the non-optimal is optimal

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Time of day effects on problem solving: When the non-optimal is optimal

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In a study examining the effects of time of day on problem solving, participants solved insight and analytic problems at their optimal or non-optimal time of day. Given the presumed differences in the cognitive processes involved in solving these two types of problems, it was expected that the reduced inhibitory control associated with non-optimal times of the day would differentially impact performance on the two types of problems. In accordance with this expectation, results showed consistently greater insight problem solving performance during non-optimal times of day compared to optimal times of day but no consistent time of day effects on analytic problem solving. The findings indicate that tasks involving creativity might benefit from a non-optimal time of day.

Keywords: Analytic; Insight; Problem solving; Time of day; Creativity.

It is well known that there are circadian or daily rhythms in basic physiological functions such as body temperature and digestive functions as well as in alertness or arousal, activity, and physical performance (e.g., Horne & Ostberg, 1976; Hrushesky, 1994). Evidence also suggests that there

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are circadian rhythms in various cognitive functions, including attention (e.g., Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1998), memory (e.g., Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1999; May, Hasher, & Stoltzfus, 1993), decision making, (e.g., Bodenhausen, 1990), and problem solving (e.g., May, 1999). The general pattern in these studies is one of better (more accurate, faster) cognitive performance at peak than at nonpeak circadian arousal when participants are completing unfamiliar or novel tasks (for an exception see May, Hasher, & Foong, 2005). This finding of better performance at peak arousal has often been referred to as the "synchrony effect", where individuals who are more alert and aroused in the morning (morning types) tend to perform better on novel tasks in the morning than in the afternoon or evening, and individuals who are more alert and aroused in the evening (evening types) tend to perform better in the afternoon or evening than in the morning (e.g., May & Hasher, 1998). An individual's "optimal time of day" is, in general, at the time of their peak circadian arousal.

INHIBITORY ATTENTIONAL CONTROL AND TIME OF DAY

Of particular relevance to the current study is the relationship between time of day and inhibitory attentional processes. Broadly speaking, inhibitory processes control the flow of information from thought and perception (e.g., Hasher & Zacks, 1988). A specific function of inhibition is to suppress the processing of distracting information to maintain consciousness or working memory relatively free of task-irrelevant or no-longer-relevant information (e.g., Hasher, Lustig, & Zacks, 2007; Hasher, Zacks, & May, 1999). This inhibitory function has been shown to be particularly affected by time of day (for a review, see Hasher et al., 2007). For unfamiliar and less practised tasks that require careful and deliberate processing synchrony effects (poorer performance during a non-optimal compared to optimal time of day) are seen. On the other hand, for tasks that rely on implicit retrieval of previous information (e.g., priming tasks) a reduction in inhibition can lead to asynchrony effects, where an increase in performance can be seen during a non-optimal compared to optimal time of day. May et al. (2005), for example, found that younger and older adults show an increase in implicit memory (assessed through stem-completion and implicit category generation tasks) during non-optimal compared to optimal times of day (the traditional synchrony effect however was observed for explicit memory). A reduction in inhibition during participants' non-optimal compared to optimal time allowed previous information to be active in working memory leading to an increase in implicit memory. Despite these impacts, a reduction in inhibition has been shown not to have an influence on tasks where participants can rely on the production of well-learned or strong

initial responses (e.g., Li, Hasher, Jonas, Rahhal, & May, 1998; May & Hasher, 1998). For example, May and Hasher found no time of day differences for the generation of highly and moderately predictable sentence endings, the accuracy and speed of category judgments, vocabulary scores, and colour naming.

The current study investigates the potential effects of differences in inhibitory control processes at optimal versus non-optimal times of the day on problem solving. May (1999) showed that inhibition, specifically the ability to control processing of distracting stimuli, affects at least one type of problem solving: the Remote Associates Task. Further, these effects were shown to vary with time of day. Participants were presented with Remote Associate words (e.g., ship, outer, crawl) along with three hint words (shown here in capital letters) that could be either misleading (e.g., ship [OCEAN], outer [INNER], crawl [FLOOR]) or leading (e.g., ship [ROCKET], outer [ATMOSPHERE], crawl [ATTIC]). Participants were instructed to ignore these hints and only focus on the main cue words. Overall it was found that misleading hints interfered with problem solving while leading hints benefited problem solving, but importantly, these costs and benefits were significantly larger at non-optimal than at optimal times of day. These results indicate that participants are less able to ignore or inhibit the additional distracting hint words during their non-optimal time of day compared to their optimal time of day. The current research extends these findings by comparing time of day effects for different problem types thought to involve different underlying processes. We show that for certain problem types reduced attentional control at a non-optimal time of day benefits performance, even in the absence of useful external hints.

INSIGHT VERSUS ANALYTIC PROBLEMS

The two types of problems of interest in the current research are insight and analytic problems. Insight problems are often solved suddenly with a "flash of illuminance" (Metcalfe & Wiebe, 1987), or what has also been called an "Aha" experience where the solution seems to just pop into mind (Schooler & Melcher, 1995). More specifically, insight problems tend to be characterised by several key features: prepotent features of a problem usually lead to an initial misrepresentation of the problem; due to the misinterpretation the solver reaches an impasse where problem solving comes to a halt because all possible solutions seem to be exhausted and the solver cannot think of a way to proceed; to move past the impasse, the solver must break away from his or her focus on the current representation of the problem and find an alternative way of structuring the problem space. This re-conceptualisation is often the key to solving an insight problem (Weisberg, 1995). Using matchstick algebra problems, Knoblich and

colleagues (Knoblich, Ohlsson, Haider, & Rhenius, 1999; Knoblich, Ohlsson, & Raney, 2001) found that once participants identified unnecessary constraints in their representation, re-representation of the problem occurred and the solution was usually found quickly.

In contrast, analytic problems (Schooler & Melcher, 1995) require the solver to "grind out the solution" by searching through and narrowing the problem space (Newell & Simon, 1972). The prepotent features of a problem usually, but not always, lead the solver to an appropriate representation and he/she moves towards the solution as different possibilities in the problem space are eliminated. When solving analytic problems the solver is working incrementally towards the solution and no restructuring of the problem space is usually necessary.

Studies examining processing during problem solving have supported the distinction between insight and analytic problems (e.g., Metcalfe & Wiebe, 1987; Schooler & Melcher, 1995; Schooler, Ohlsson, & Brooks, 1993). For example, Metcalfe and Wiebe (1987) asked participants to rate how close they thought they were to the solution every 15 seconds while solving analytic and insight problems. Problem solvers had a good idea when they were close to the solution for analytic problems, but were unable to perceive when they were close to a solution for insight problems. Solutions for insight problems came suddenly and with little awareness that the solution was about to be found. Additionally, insight and analytic problem solving have been shown to differ in brain activation (e.g., Bowden, Jung-Beeman, Fleck, & Kounios, 2005; Lavric, Forstmeier, & Rippon, 2000). Bowden et al. found greater neural activity over the temporal lobes when solving insight problems while there was greater neural activity over the posterior cortex while solving analytic problems. Similarly, Lavric et al. (2000) found greater ERP activation in the frontal region of the brain when participants were completing a counting task while solving an analytic problem compared to an insight problem. These differences in brain activation provide further evidence for the distinction between analytic and insight problem solving processes.

PROBLEM SOLVING AND TIME OF DAY

As discussed above, research has shown that non-optimal time of day is associated with reduced inhibitory attentional control and that this reduced control can affect some types of problem solving, as shown by May (1999). A key aspect of successful insight problem solving is the ability to overcome an impasse. That is, to solve an insight problem participants need to reinterpret the problem and approach it from a different perspective. Given that May et al. (2005) found evidence that participants are more influenced by previous information during their non-optimal compared to optimal time

of day, it is possible that a non-optimal time of day is also beneficial for insight problem solving.[1] By permitting the consideration of a larger range of information and by reducing focus on the initial wrong interpretation, participants' relative inability to selectively focus and to control information entering working memory might help individuals reinterpret the problem and overcome the impasse seen in insight problem solving. It was therefore hypothesised that non-optimal time of day participants will show greater insight problem-solving rates than optimal time of day participants. Due to the differences in the underlying problem-solving processes, a different pattern of results is expected for analytic problems. When solving analytic problems the prepotent features of a problem will most likely lead to an initial representation that is correct and does not need to be restructured before the problem can be solved. May and Hasher (1998) showed that tasks where the initial response or approach is correct tend to be spared from time of day effects. Therefore as long as the problem solver has the correct initial representation, no time of day effects should be seen.

METHOD

Participants

A total of 428 students from a large Midwestern university participated for course credit (mean age 20.41, $SD = 1.91$). Based on a morningness/eveningness self-report measure by Horne and Ostberg (1976), 195 participants were evening type individuals, 28 were morning type individuals, and 205 were neutral type individuals. These findings are in line with normative studies showing that university aged adults are much more likely to be evening and neutral than morning individuals (May et al., 1993; Mecacci, Zani, Rocchetti, & Lucioli, 1986).

Materials

Morningness Eveningness Questionnaire (MEQ). The MEQ by Horne and Ostberg (1976) is a self-report measure used to determine a participant's optimal time of day; it contains questions about sleep habits, peak performance, and other circadian functions. The answers to these questions are compiled into a score that ranges from 16 to 86 and corresponds to one

[1]A small pilot study with 34 participants investigated the effect of time of day on insight problem solving. Results showed that participants in the non-optimal condition had a significantly higher overall solution rate ($M = .51$) than participants in the optimal condition ($M = .26$), $t(32) = 2.68$ $MS_e = .09$, $p = .01$, $\eta^2 = .18$.

of five categories: definitely evening type (16–30), moderately evening type (31–41), neutral (42–58), moderately morning type (59–69), and definitely morning type (70–86). Previous research has shown strong correlations between scores obtained on the MEQ and measures of arousal, such as sleep/wake behaviours, body temperature, basal skin conductance, and heart rate (Adan, 1991, Horne & Ostberg, 1976, Kerkhof, van der Geest, Korving, & Rietveld, 1981). Additionally, the MEQ has been show to be a valid indicator of circadian arousal (e.g., Smith, Reilly, & Midkiff, 1989) and to have high test–retest reliability (e.g., Anderson, Petros, Beckwith, Mitchell, & Fritz, 1991).

Insight and analytic problems. Participants completed three insight and three analytic problems (see Appendix) selected from Metcalfe and Wiebe (1987) and Wieth and Burns (2006). The analytic problems used were the *Age* problem, the *Bachelor* problem, and the *Flower* problem. These problems can all be solved by working incrementally towards the solution. The insight problems used were the *Fake Coin* problem, the *Prisoner* problem, and the *Water Lilies* problem. They were chosen because all require a re-representation of the problem space in order to find the solution.

Procedure

Participants were randomly assigned to either a morning testing session (between 8:30 am and 9:30 am) or a later afternoon testing session (between 4 pm and 5:30 pm). Participants were tested in group sessions (ranging from two to seven participants). Participants completed a background questionnaire and were then given the first problem. They were told that they had 4 minutes to try to solve the problem presented at the top of a sheet of paper that participants could use to work out their solution. Once 4 minutes were up, participants were reminded to circle their answer and the experimenter collected the answer sheet. Participants completed a total of six problems and were randomly assigned to one of four orders. To prevent mental set, the four orders were designed such that analytic and insight problems alternated throughout the presentation of the problem set. Other than this limitation, the orders were created randomly. Once participants completed the problems, they filled out the MEQ.

RESULTS

Two raters, blind to condition, scored all problems as either correct (1) or incorrect (0). The raters followed strict scoring guidelines that instructed them to score a problem as correct only if the answer clearly matched the

solution provided on a scoring sheet. Inter-rater reliability was found to be quite satisfactory ($K = .91$). In order to analyse the data an analytic problem-solving score was calculated as the proportion correct of the three analytic problems attempted, and an insight problem-solving score as the proportion correct of the three insight problems attempted.

Consistent with previous research (e.g., May & Hasher, 1998; Yoon, 1997), only the 223 participants with a clear circadian time preference were included in the main analyses (excluding neutral types). For the purpose of this study definitely and moderately type categories were combined, creating a morning type group and an evening type group leaving 28 morning and 195 evening types. A 2 × 4 × 2 mixed analysis of variance was performed on the analytic and insight scores with between-participants factors of time of day (optimal or non-optimal) and order (the four orders described above), and a within-participants factor of problem type (insight and analytic). Note that although our data were ordinal we used an ANOVA rather than a log-linear modelling analysis. Lunney's (1970) simulations showed that ANOVA can be validly used for analysing this type of data when the sample size is sufficiently large. Using an ANOVA also allows us to take advantage of the fact that participants completed more than one problem, which is more problematic for log-linear analysis with its strong assumption of independence. Results showed that there was no evidence of an effect of order or any interactions with order (all Fs < 1.1). Therefore all further analyses are shown pooled over this variable.

As can be seen in Figure 1, there is a significant effect of problem type, $F(1, 221) = 8.65$, $MS_e = .63$, $p = .004$, $\eta^2 = .04$, indicating the participants were overall more successful at solving analytic problems than insight problems. There was no significant effect of time of day, $F(1, 221) = 1.06$, $MS_e = .10$, $p = .304$, $\eta^2 = .01$, indicating that participants solving problems at their optimal time of day did not differ from participants solving problems at their non-optimal time of day. However, these effects are qualified by a significant interaction between problem type and time of day, $F(1, 221) = 6.51$, $MS_e = .47$, $p = .011$, $\eta^2 = .03$. Follow-up tests showed that analytic problem-solving performance did not differ across time of day, $t(221) = .95$, $MS_e = .08$, $p = .342$, $\eta^2 = .004$, such that participants' performance in the non-optimal condition ($M = .43$) did not differ from participants' performance in the optimal condition ($M = .47$). Insight problem-solving performance, on the other hand, showed a significant difference across time of day, $t(221) = 2.37$, $MS_e = .09$, $p = .019$, $\eta^2 = .03$. More specifically, participants in the non-optimal condition ($M = .42$) had a higher insight problem solution rate than participants in the optimal time of day condition ($M = .33$). Looking at the effect of time of day on individual problem solution rates (see Table 1), one can see that insight problem solving was consistently greater at a participants' non-optimal time of day

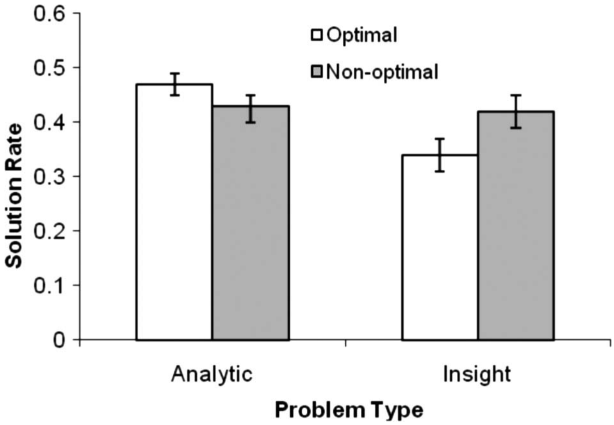

Figure 1. Solution rates (proportion correct) for insight and analytic problems during participants' optimal and non-optimal times of day. Error bars represent standard error of the mean.

TABLE 1
Proportion correct for each problem solved during optimal and non-optimal times of day

	Non-optimal (n = 100)	*Optimal (n = 123)*
Insight 1 (Prisoner)	.56 (.50)	.51 (.50)
Insight 2 (Fake Coin)	.22 (.42)	.16 (.37)
Insight 3 (Lilies)	.49 (.50)	.31 (.46)
Analytic 1 (Age)	.26 (.44)	.28 (.45)
Analytic 2 (Bachelor)	.35 (.48)	.35 (.48)
Analytic 3 (Flower)	.69 (.47)	.77 (.42)

Standard deviations in parentheses

compared to optimal time of day. This consistency was not seen for analytic problem solving, as two analytic problems showed no optimal benefit while the third problem showed a moderate optimal benefit when comparing performance between an optimal and non-optimal time of day.

DISCUSSION

Time of day effects occur in many physiological and cognitive areas. Much research has shown that when the time of day is in synchrony with a person's circadian arousal, better performance on unfamiliar tasks is seen than during a time not in synchrony with a person's circadian arousal (e.g., Intons-Peterson et al., 1998, May et al., 1993). However, aspects of the

present study showed the opposite result. Participants who solved insight problems during their non-optimal time of day, when arousal is lower, were more successful than participants at their optimal time of day. These findings provide evidence that a non-optimal time of day can be beneficial to certain problem-solving tasks. Additionally, the results further support research by May et al. (2005) showing that certain cognitive functions benefit from a non-optimal time of day. The contrast between insight and analytic problem-solving performance across the two time periods also shows that the benefit seen for insight problem solving during a non-optimal time period is most likely tied to problem-solving processes associated with insight problems. Whereas an overall benefit for a non-optimal time of day is seen for insight problems, no overall difference across the two time periods is seen for analytic problems. These findings may be related to results obtained by Sio and Ormerod (2009) who showed that creative problems are more likely to benefit from an incubation period compared to problems that are solved by retrieving a specific strategy to reach a solution. Similar to a non-optimal time of day, an incubation period is believed to lead to a more diffuse attentional focus associated with participants widening their search though their knowledge network. This widening leads to an increase in creative problem solving but does not facilitate problem solving for analytic type problems for which the solution lies within already activated knowledge. Because insight problems have been shown to involve a certain amount of creativity (Dominowski, 1995), it is possible that time of day and incubation impact similar cognitive processes involved in problem solving.

When examining the individual problem solution rates, it is evident that the insight solution rates do not follow the same pattern as the analytic solution rates. As can be seen in Table 1 all insight problem solution rates are greater for the non-optimal time of day than the optimal time of day condition, while analytic problem solution rates either remain constant across the two time conditions or show an increase in the optimal time of day condition. These findings are consistent with previous research showing that tasks with strong initial responses (such as forming a representation based on the prepotent features of a problem) are not affected by time of day differences (e.g., Li et al., 1998; May & Hasher, 1998). Analytic compared to insight problem solving tends to rely more on the execution of initial responses which potentially led to time of day having less of an impact.

When looking at the individual problem solution rates it is also evident that one analytic problem, the *Flower problem,* shows a potential benefit (though not significant), $t(221) = 1.39$, $MS_e = .18$, $p = .17$, $\eta^2 = .01$, of an optimal compared to a non-optimal time of day while solution rates for the other two analytic problems remain fairly constant across time of day. Similarly, when examining the individual solution rates of the insight problems, one problem, the *Lilies problem*, seems to be particularly affected

by time of day (though in the predicted direction). This inconsistency across individual problems, despite the pattern still being consistent with our argument that time of day influences insight and analytic problems differently, is most likely due to ancillary differences among the problems themselves (e.g., difficulty, complexity, reliance on working memory). The *Flower problem* for example, seems to be less difficult (*M* across time of day = .73) than the remaining problems in the study. It is therefore possible that difficulty may play a role when investigating the impact of time of day on problem solving. Future research could explore the impact of these ancillary factors by using problems whose difficulty can be more easily controlled (e.g., compound remote associates problems).

Although the pattern of results in this study indicates that time of day influences insight and analytic problems differently, it should be noted that MacGregor, Ormerod, and Chronicle (2001) have argued that the same underlying cognitive processes are used when solving insight and analytic problems. More specifically, MacGregor et al. (2001) have proposed that insight problems, just like analytic problems, can be solved using a hill-climbing heuristic approach, where the problem solver seeks to minimise the gap between the current state of the problem and the goal state. Using the classic nine-dot problem, Chronicle, Ormerod, and MacGregor, (2001) and MacGregor et al. (2001) showed that participants examine the difference between the current state of the problem and the goal state and compare this with the number of legal problem-solving moves remaining. An impasse, or criterion failure, occurs when there is a large distance between the problem state and the goal state with only a small number of moves remaining. It is at this point when the problem solver realises that the remaining moves will not lead to a solution and he/she will most likely seek an alternative approach. While the progress-monitoring theory (MacGregor et al.) is clearly a different conceptualisation of insight problem solving than the more traditional representational change theory (e.g., Knoblich et al., 2001), the impact of a reduction in inhibition at a non-optimal time of day may actually be similar. As participants are using the hill climbing method, weakened inhibitory control during a non-optimal time of day may lead to serendipitous discoveries of new ideas for insight problems that may lead to a solution. Analytic problems, on the other hand, do not need discovery of new ideas and therefore remain unaffected by time of day. These processes would still lead to an increase in insight problem solving and no differences for analytic problems during a non-optimal compared to optimal time of day. Using a car-park insight problem, Jones (2003) tested the traditional representational change theory of insight problem solving (e.g., Knoblich et al., 2001) and the progress-monitoring theory proposed by MacGregor and colleagues, and found evidence for both constraint relaxation, associated with the representational change theory, and criterion shifting,

associated with the progress-monitoring theory. It is therefore possible that participants in the current study were able to use both approaches to insight problem solving and both approaches are influenced by a reduction in inhibitory control.

Given the nature of our participants—mostly evening type individuals tested either in the morning (non-optimal) or the evening (optimal)—the possibility that the non-optimal benefit for insight problem solving is due to a general morning effect and not an optimality effect needs to be considered. Whereas the demographics for our sample are consistent with previous research using undergraduates (morning individuals are rare among undergraduates), it does open the possibility that simply solving insight problems in the morning (regardless whether this is a participant's optimal or non-optimal time of day) leads to greater problem-solving rates. In order to address this we examined the performance pattern of the neutral individuals who completed this study but were not included in any of the original analyses. Given neutral individuals' general lack of strong time of day preferences and their relatively constant arousal and performance levels across the day (Horne & Ostberg, 1976), we would expect no testing time effects on insight problem solving. On the other hand, if there is something specific about being tested in the morning (i.e., a morning effect) then the neutral individuals should also show greater insight problem solving in the morning than the evening. Results showed no effect of the time (morning or evening) on neutral participants' solution rates, $t(203) = .98$, $MS_e = .10$, $p = .33$, $\eta^2 = .01$. Neutral participants tested in the morning ($M = .38$) did not have a greater insight solution rate than neutral participants tested in the evening ($M = .34$)—the same pattern of results was observed for the analytic solution rates, $t(203) = 1.17$, $MS_e = .09$, $p = .25$, $\eta^2 = .01$. In addition, although the small numbers hinder any strong inferences, we found that among the morning types, the subgroup ($n = 9$) tested in the morning did not outperform the subgroup ($n = 18$) tested in the evening for either insight or analytic problems. These findings do not completely rule out the possibility that our results are due to something specific about being tested in the morning; however, they strongly imply that the non-optimal benefit in insight problem solving is most likely due to differences in arousal and not simply a morning effect.

The findings of this study also have several broader implications. Due to the connection between insight problem solving and creativity (Dominowski, 1995) it is possible that tasks that require a creative approach might benefit from asynchrony. Perhaps reduced inhibitory effects associated with a non-optimal time lead individuals to consider new approaches to a task that ultimately produce better solutions. This suggests that students designing their class schedules might perform best in classes such as art and creative writing during their non-optimal compared to optimal time of

day. Previous research has shown that students tend to get higher grades when classes are in synch with their circadian arousal (e.g., Guthrie, Ash, & Bendapudi, 1995); however, the interaction between time of day and type of class has not been investigated. The results of this study suggest that the relationship between time of day and grades needs to be investigated and may not simply follow a uniform pattern.

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APPENDIX

Insight problems

Prisoner problem

A prisoner was attempting to escape from a tower. He found in his cell a rope that was half long enough to permit him to reach the ground safely. He divided the rope in half, tied the two parts together, and escaped. How could he have done this?

Fake Coin Problem

A dealer in antique coins got an offer to buy a beautiful bronze coin. The coin had an emperor's head on one side and the date 544 BC stamped on the other. The dealer examined the coin, but instead of buying it, he called the police. Why?

Water Lilies Problem

Water lilies double in area every 24 hours. At the beginning of the summer there is one water lily on a lake. It takes 60 days for the lake to become completely covered with water lilies. On what day is the lake half covered?

Analytic problems

Age Problem

Bob's father is 3 times as old as Bob. They were both born in October. 4 years ago, he was 4 times older. How old are Bob and his father?

Bachelor Problem

Five bachelors, Andy, Bill, Carl, Dave, and Eric, go out together to eat five evening meals (Fish, Pizza, Steak, Tacos, and Thai) on Monday through Friday. It was understood that Eric would miss Friday's meal due to an out of town wedding. Each bachelor served as the host at a restaurant of his choice on a different night. The following information is known:

- Carl hosted the group on Wednesday.
- The fellows ate at a Thai restaurant on Friday.
- Bill, who detests fish, volunteered to be the first host.
- Dave selected a steak house for the night before one of the fellows hosted everyone at a raucous pizza parlour.

Which bachelor hosted the group each night and what food did he select?

Flower Problem

Four women, Anna, Emily, Isabel, and Yvonne, receive a bunch of flowers from their partners, Tom, Ron, Ken, and Charlie. The following information is known:

- Anna's partner, Charlie, gave her a huge bouquet of her favourite blooms; which aren't roses.
- Tom gave daffodils to his partner (not Emily).
- Yvonne received a dozen lilies, but not from Ron.

What type of flowers (carnations, daffodils, lilies, or roses) were given to each woman and who is her partner?